

# Teck Highland Valley Copper Partnership

**Highland Tailings Storage Facility** 

L-L Dam Breach and Inundation Study for Dam at El. 1279 m







October 31, 2014

Teck Highland Valley Copper Partnership PO Box 1500 Logan Lake, British Columbia VOK 1W0

Mr. Chris Fleming
Superintendent, Tailings and Water Management

Dear Mr. Fleming:

Highland Tailings Storage Facility
L-L Dam Breach and Inundation Study for Dam at El. 1279 m

We are pleased to submit our final report on the dam breach and inundation study for the L-L Dam based on a dam crest elevation of 1279 m, which is the currently permitted ultimate dam height.

Unlike previous inundation studies, the computer model for the current study was extended upstream along the Thompson River to Ashcroft and downstream along the Fraser to Laidlaw. Laidlaw is located approximately 15 km downstream of Hope, and the results of the dam breach and inundation analyses indicate that the dam breach flood would be substantially reduced by the time it reaches Laidlaw.

Please contact me if you have any questions.

Yours truly,

KLOHN CRIPPEN BERGER LTD.

Arvind Dalpatram, P.Eng.

**Project Manager** 

AD: cd



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#### **EXECUTIVE SUMMARY**

The Executive Summary is provided solely for purposes of overview. Any party who relies on this report must read the full report. The Executive Summary omits a number of details, any one of which could be crucial to the proper application of this report.

The Highland Valley Copper Mine is located approximately 15 km west of Logan Lake, British Columbia. The mine produces copper through a hard rock mining process which involves the grinding of the mined rock into fine particles such that copper can be extracted. The rock is generally ground into particles the size of sand or smaller. The fine material left after the copper is extracted is called tailings. The tailings from the current mine operation are impounded in the Highland Tailings Storage Facility (TSF), and are transported from the mill to the TSF as a slurry (a mixture of fine particles and water) by a pipeline.

The Highland TSF is located in the head waters of Pukaist Creek, and it has been in operation since 1972. The TSF is a long, narrow impoundment (9.5 km long, and 1.5 km to 3.0 km wide) and it has two dams which hold the tailings within the TSF: the H-H Dam located at the east end of the TSF; and the L-L Dam located at the west end. The total volume of tailings in the TSF is currently 1.35 billion tonnes, and ultimately it will have 2.1 billion tonnes of tailings corresponding to an ultimate dam height of 181 m.

#### **Dam Breach and Inundation Study**

The Canadian Dam Safety Guidelines (2007) recommend that dam breach and inundation studies be completed for all water and tailings dams. These studies consider potential consequences of hypothetical dam breaches on areas downstream of the dam. The consequences are evaluated in terms of incremental impacts, which are defined in the Dam Safety Guidelines as the damage above and beyond the damage that would have occurred in the same conditions had the dam not breached. The consequences of dam breach are divided into three categories, which include: loss of life; loss of environmental and cultural values; and infrastructure and economic losses. The results of the dam breach and inundation analyses are used to establish the breach consequence classification of the dam, and in the development of the emergency preparedness and response plan (EPRP). The EPRP would be activated in the event there is an incident at the dam.

The Dam Safety Guidelines specify five dam consequence classifications: Low, Significant, High, Very High and Extreme. The Low classification is assigned to dams which would result in very low consequences due to the breach of the dam. The Extreme classification is assigned to dams which would result in very severe consequences due to the dam breach. Dams classified as Extreme are designed to stringent design criteria, and are subjected to the most stringent operation, maintenance and surveillance requirements in the Dam Safety Guidelines. The L-L Dam is assigned an Extreme consequence classification, and the dam has been designed, constructed and operated accordingly.

The top of L-L Dam (i.e., the crest of the dam) is currently at El. 1257.6 m, and the dam is raised annually to meet tailings and water impoundment requirements. This report presents the dam breach and inundation study for the L-L Dam with the crest at the permitted elevation of 1279 m (a

dam height of 181 m). This study analysed hypothetical breaches of the L-L Dam and the potential consequences primarily for the purpose of informing and updating the existing EPRP for the dam. The dam breach and inundation analyses completed for the L-L Dam are based on hypothetical modes of breach under extreme and highly unlikely conditions and, as such, the results of the analyses presented herein in no way reflect upon the structural integrity or safety of the dam.

The flood released from a hypothetical L-L Dam breach would flow along the following route:

- 11 km along Pukaist Creek and Coldstream Creek from the dam to the Thompson River;
- 46 km along the Thompson River from the Thompson River/Pukaist Creek junction to Lytton, where the Thompson River flows into the Fraser River; and
- 260 km along the Fraser River from Lytton to the Strait of Georgia at Richmond.

Major tributaries along the modelled flood route include: the Nicola River which flows into the Thompson River near Spences Bridge; and the Coquihalla River which flows into the Fraser River at Hope. The study considered related upriver flooding (backwatering) into these tributaries, as well as along the Thompson River upstream of Pukaist Creek and along the Fraser River upstream of the Thompson River.

Populated areas within the modelled study area are: the community at the junction of Nicola and Thompson Rivers, and the towns/villages of Spences Bridge, Lytton, Boston Bar, Spuzzum, Yale, Hope and Laidlaw. There are also scattered farmlands along the Thompson, Nicola and Fraser Rivers.

The Thompson and Fraser River valleys within the study area are major transportation corridors which carry the Trans-Canada Highway and two national railways. These rivers are major migratory routes for fish used for First Nations food fishing, and commercial and recreational fishing.

## **Computer Model Analyses**

The HEC-RAS computer model developed by the US Army Corps of Engineers was used for the dam breach and inundation analyses. This model is widely used and is considered to be one of the industry standard models. The computer model has two components:

- The first component simulates the dam breach and estimates the volume and the rate at which the water and tailings are released from the dam.
- The second component simulates the movement of the released tailings and water along the flood route downstream of the dam, and it provides estimates of the areas that could be flooded; the time it takes for the flood wave to reach key locations; the peak flood flows and maximum water levels along the flood route; the time it takes for the water level to rise to its maximum level; and the time it takes for the water level to drop back to original level that was in the river before the arrival of the dam breach flood wave.



The latter information is particularly useful for emergency preparedness and response planning purposes.

The model for the L-L Dam encompassed the sections of Pukaist Creek and Thompson River mentioned above, plus approximately 130 km of the Fraser River from Lytton to Laidlaw. Laidlaw is located about 15 km downstream of Hope. The model also included 33 km of the Thompson River between Pukaist Creek and Ashcroft, 12 km of the Nicola River upstream of the Thompson River, 28 km of the Fraser River upstream of the Thompson River, and 7 km of the Coquihalla River upstream of the Fraser River to assess the backwater effects.

As outlined in the Dam Safety Guidelines, two dam breach scenarios were assessed for the L-L Dam: a "sunny-day" scenario; and a "rainy-day" scenario. Sunny-day breach scenarios are assumed to occur when the water behind the dam is at its normal (non-flood) operating level. Examples of sunny day scenarios include a slump of the dam slope during a major earthquake, or a breach of the dam caused by internal erosion of dam fill. For sunny-day scenarios, the flows in the rivers downstream of the dam are assumed to be equal to their Mean Annual Flows (MAF). The Mean Annual Flow is the estimated or recorded average flow in the river.

Rainy-day scenarios occur when rain and/or snowmelt inflow to the pond is so large that it causes the pond water level to rise above a level that the dam can safely accommodate. For the L-L Dam, the dam was assumed to be overtopped such that the upper bound consequences of the breach could be determined for emergency response planning purposes. For rainy-day scenarios the ambient flows in the rivers downstream of the dam are assumed to be under flood conditions. For this study, the ambient river flows were assumed to be equal to their Probable Maximum Flood (PMF) flows. The PMF is the largest flood that can be reasonably expected to occur at a particular location, and it is regarded as the upper flood limit. The PMF is estimated through analyses of potential maximum rainfall and/or snowmelt.

The Highland TSF is operated as a closed facility, where no surface water is released from the TSF to the environment. The TSF has sufficient capacity to store not just the average annual flood but the PMF as well. In addition to the flood storage capacity, the facility has an additional 3 m of extra allowance (called freeboard) between the highest expected flood storage level and the top of the dam. Therefore, for the L-L Dam to be overtopped, the flood inflow would have to be almost double the PMF volume which is a highly unlikely scenario.

To identify the maximum effects of flooding for the rainy-day scenarios, the dam breach flood was combined with the PMF from the full catchments of the four receiving rivers (the Thompson, Nicola, Fraser and Coquihalla). Given the large catchment areas, a PMF occurring at the same time in all four watersheds is highly unlikely. The use of the full catchment PMF results in much larger inundation areas than what would be reasonably expected but was used to provide guidance for the EPRP.

During mine operations, tailings are transported from the mill to the TSF as a slurry, which is a mixture of solids and water. The tailings solids tend to settle to the bottom and a water pond forms on top of the tailings solids. If a tailings dam breaches, not all the tailings impounded behind the dam are released. Based on the potential breach scenarios, the geometry of the impoundment (the

Highland TSF is a long, narrow impoundment), the dam height, and comparison to historical dam breaches, 10% of the tailings in the TSF was estimated to be released.

Dam breach and inundation modelling considers dam breach scenarios and then estimates the water and tailings flows that would follow. The model is based on estimates of input parameters such as the time it takes for the dam to breach (breach formation time), the size of the breach in the dam (breach width, breach depth and breach side slopes), and the roughness of the river channel along the flood route. Computer runs consider a "base case" scenario, plus additional "sensitivity" analyses by varying the input parameters to see how the results would change. During a tailings dam breach, there is usually an initial rapid release of clear and/or tailings laden water followed by a more prolonged release of mobilized tailings. For modeling purposes, the released tailings were assumed to flow like water. This is a conservative assumption since the tailings released would have mud like characteristics and would not flow as readily as water. This provides an upper boundary to the potential inundation areas for emergency preparedness and response planning purposes.

Dam breach scenarios with the release of only the water from the impoundment were also considered in order to ascertain the lower boundaries of potential consequences downstream of the dam. However, the results of the scenarios which assume both the water and the tailings are released, which are considered to be conservative and form the upper bound consequences, will be used for emergency preparedness and response planning purposes.

The computer model for the L-L Dam breach was terminated at Laidlaw because the results of the dam breach and inundation analyses indicate that the dam breach flood for the sunny-day scenario would be less than the 200-year flood by the time it reaches Laidlaw. The 200-year flood is a flood which is expected to occur in a river on average every 200 years, and it is the design standard for flood protection works in British Columbia. The results also indicate that the incremental consequences at Laidlaw for the rainy-day scenario would be negligible.

#### **Results of Analyses**

The results of the dam breach and inundation analyses for the L-L Dam indicate that the flood wave for both rainy-day and sunny-day scenarios will move quickly along the flood route downstream of the dam. The flood arrival times depend on the dam breach scenario being analysed, the distance from the dam, and the input parameters such as ambient flow conditions in the rivers, the breach formation time and the river channel roughness. Flood arrival times along the flood route for various dam breach scenarios and input parameters are shown in Figures 5.8, 5.9 and 5.19. The ranges of flood arrival times for Spences Bridge, Lytton and Hope are summarized in the following table. The flood arrival time shown is the time it takes for the front end of the flood wave to reach a particular location after the initiation of the breach at the dam. Depending on the dam breach scenario, the ambient flow conditions in the river and the location along the flood route, it would take approximately 1 hour to 11.5 hours for the flood to arrive. Given the relatively short flood arrival times, the opportunity to issue flood warnings in a timely manner after the breach is initiated would be limited, particularly for areas close to the dam such as Spences Bridge.

Table 1 Flood Arrival Times

Location	Sunny-Day Scenario (hours)	Rainy-Day Scenario (hours)				
Spences Bridge	1.3 to 1.9	1.0 to 1.9				
Lytton	2.5 to 4.0	1.5 to 2.5				
Норе	6.9 to 11.5	3.4 to 4.5				

Depending on the dam breach scenario, the ambient flow conditions in the river and the location along the flood route, it would take approximately 1 hour to 5 hours for the flood water to rise to its maximum level after arrival of the front end of the flood wave.

As the flood wave moves further downstream from the dam, the peak flood flow becomes smaller because the flood is attenuated along the flood route. The dam breach flood for the sunny-day scenario was reduced to less than the 200-year flood by the time the flood reached Laidlaw, and the incremental consequences for the rainy-day scenario were reduced to negligible levels at Laidlaw and points further downstream.

In order to assess the consequence classification of a dam breach, the peak water levels and the risk to existing infrastructure (roads, railways, buildings, etc.) and the potential loss of life were reviewed. A preliminary review of environmental impacts was also carried out. A cultural and environmental effects assessment is being conducted under a separate study.

In the sunny-day scenario, a breach of the L-L Dam would have significant incremental impacts downstream of the dam. Numerous sections of the railways and roads adjacent to the Thompson and Fraser Rivers and many houses and other buildings in the communities and rural areas downstream of the dam would be flooded (see Figure 5.5 for flood inundation maps, and Table 5.7 for estimates of population and structures within the modelled inundation zone).

In the rainy-day scenario, there would already be widespread flooding due to the naturally occurring PMF along the rivers downstream of the dam. Highways, railways, communities and farms would be flooded. The incremental inundation of the dam breach over and above the inundated area caused by the ambient PMF are considered to be moderate because the areas subjected to flooding with the dam breach would already experience widespread flooding under naturally occurring PMF conditions without a dam breach (see Figure 5.5 for flood inundation maps, and Table 5.7 and Table 5.8 for estimates of population and structures within the modelled inundation zone).

Sunny-day breaches (such as those triggered by an earthquake) tend to occur quickly, whereas rainy-day breaches may take longer to develop. For a rainy-day breach, routine monitoring of the TSF would note the rising water level in the pond such that sufficient warning of an impending flood would be provided. The risk of loss of life under a sunny-day scenario could be higher than under a rainy-day scenario because it might not be possible to issue a warning of impending flood in a timely manner.

Based on the results of this dam breach and inundation study, the L-L Dam is classified as Extreme, and no design update for the dam is required because it is already designed, constructed and

operated under that classification to the most stringent standards outlined in the Canadian Dam Safety Guidelines.

#### Limitations

The dam breach and inundation analyses are based on hypothetical scenarios, and the conditions under which these scenarios occur are considered highly unlikely. The model has used assumptions, such as tailings behaving like water and the use of a province-wide PMF, that are conservative. Based on the use of industry standard modeling methods and software, conservative assumptions, and unlikely breach scenarios, the inundation prediction for a rainy-day scenario occurring during a PMF is considered upper bound and suitable for comprehensive emergency preparedness and response planning. The requirement to carry out this analysis does not reflect on the structural integrity or safety of the L-L Dam.

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## 1 INTRODUCTION

Klohn Crippen Berger Ltd. (KCB) was retained by Teck Highland Valley Copper Partnership (Teck HVC) to undertake dam breach and inundation analyses for the L-L Dam at the Highland Tailings Storage Facility (TSF). Current mine plan calls for deposition of tailings in the TSF up to year 2028, which has a projected ultimate L-L Dam crest elevation of 1279 m. The projected dam height is based on impounded tailings volume, operating water and flood storage requirements, plus freeboard (KCB, 2010). A dam breach and inundation study was completed in 2012 for the L-L Dam with its crest at El. 1279 m (KCB, 2012b). The 2012 study area covered Pukaist Creek and Thompson River up to 12 km downstream of Spences Bridge. The purpose of this report is to extend the study area to determine the full extent of the flood effects up to Laidlaw as described in Section 2. This report supersedes the previous dam breach and inundation study report.

As recommended by the Dam Safety Guidelines published by the Canadian Dam Association (CDA, 2007), dam breach and inundation studies are done for all major water and tailings dams. These studies consider hypothetical dam breaches and assess potential impacts of the breach on areas along the receiving waters downstream of the dam relative to guidelines and criteria established for dam safety. The modeled impacts relative to consequence levels in the dam safety guidelines are used to establish the design criteria for the dam. The results of the dam breach and inundation analyses are also used as input for the emergency preparedness and response plans (EPRPs). The L-L Dam has already been designed for the highest consequence classification (Extreme) presented in the Dam Safety Guidelines and the British Columbia Dam Safety Regulation, and the results of this study would not alter the design criteria for the dam. The primary goal of this study was to ascertain the potential inundation areas and consequences of hypothetical breaches of L-L Dam for the purpose of informing and updating the existing EPRP for the dam. Therefore, very conservative parameters have been used for this study in order to ascertain the worst case conditions with respect to the EPRP for L-L Dam. As such, some of the dam breach and inundation scenarios presented in this report are considered to be highly unlikely to occur.

A hydraulic model was used to estimate outflows resulting from a breach of L-L Dam, and the outflow was routed along the streams downstream of the dam to estimate flood flows, flood depths and the likely extent of flooding downstream of the dam. Two dam breach scenarios (a rainy-day breach and a sunny-day breach) were considered as described in Section 4.2. Typically the flooding levels are compared to natural water levels in the receiving streams commensurate with the assumed flow condition at the time of dam breach. A sensitivity analysis to ascertain the effects of selected parameters on the results was conducted by varying Manning's roughness coefficient (n), breach formation time and breach elevation.

This report was prepared by Klohn Crippen Berger Ltd. for the account of Teck Highland Valley Copper Partnership. The material in it reflects Klohn Crippen Berger's best judgement in light of the information available to it at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Klohn Crippen Berger Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

## 2 PROJECT SETTING

## 2.1 Dam Description and Location

The Highland Valley Copper Mine is located approximately 15 km west of the town of Logan Lake, British Columbia. The Highland TSF is located on Pukaist Creek north-west of the mine pit, and it has been in operation since 1972. The TSF is a long, narrow impoundment about 9.5 km long and 1.5 km to 3.0 km wide. The impoundment is retained by the L-L Dam at the downstream (west) end and the H-H Dam at the upstream (east) end, as shown in Figure 2.1. The L-L Dam is a zoned earthfill embankment constructed by the centreline method. It is raised annually and is currently approximately 160 m high with a crest elevation of about 1258 m. A typical dam cross-section is presented in Figure 2.2. The L-L Dam includes a Starter Dam constructed to El. 1146 m. The Starter Dam has a central core of glacial till and upstream and downstream shells of more pervious glacial till and glaciofluvial outwash sands and gravels. The section of L-L Dam above the Starter Dam has a 15 m wide centreline glacial till core and downstream and upstream shells consisting of compacted cycloned sand fill. The slope of the downstream face of the dam ranges from 2H:1V to 3H:1V with significant benches and berms to increase dam stability. The overall slope of the downstream dam face is 2.5H:1V, or flatter. The upstream dam shell does not have a clearly defined face. The cycloned sand fill is intermixed with hydraulically placed tailings sand through a zigzag transition zone, however the effective slope of the upstream face has been assumed to be similar to the downstream face for the purpose of the dam breach analyses.

The majority of the tailings are spigotted into the TSF from the H-H Dam, and the H-H Dam is always kept higher than the L-L Dam. The supernatant (free water) pond for the TSF is located close to the L-L Dam.

The dam breach and inundation analyses presented in this report considered the breach of L-L Dam only. A dam breach study for the H-H Dam has been completed by others.

# 2.2 The Study Area and Downstream Drainage Network

The flood route downstream of the L-L Dam consists of the following:

- 11 km along Pukaist Creek from L-L Dam to the Thompson River;
- 46 km along the Thompson River from the Pukaist Creek/Thompson River confluence to Lytton; and
- 260 km along the Fraser River from Lytton to Richmond. The Fraser River discharges into the Strait of Georgia at Richmond.

Flood routing for dam breach inundation mapping is usually carried to a point beyond which flooding would no longer constitute a hazard to life and/or property. The location where this occurs cannot be determined with any certainty until the dam breach and inundation analysis is completed, therefore the study area for L-L Dam was incrementally increased as modelling work progressed: first downstream to Boston Bar and then downstream to Laidlaw on the Fraser River. The study area was

also extended upstream along the Thompson River up to Ashcroft. The final hydraulic model included the following downstream reaches:

- approximately 11 km along Pukaist Creek, which discharges into the Thompson River;
- approximately 46 km along the Thompson River, which discharges into the Fraser River at Lytton; and
- approximately 130 km along the Fraser River to Laidlaw, which is located about 15 km downstream of hope.

A flood resulting from a breach at the L-L Dam is also expected to backwater in the Thompson River upstream of Pukaist Creek, in the Nicola River upstream of the Nicola/Thompson confluence, in the Fraser River upstream of the Fraser/Thompson confluence (at Lytton), in the Coquihalla River upstream of the Coquihalla/Fraser confluence (at Hope), and in the tributaries of these rivers. The depth and distance of backwatering depends on the magnitude of the flood released from the dam, the concurrent river flow conditions and the river geometry. To assess the backwater effects, the following river reaches were also included in the hydraulic model:

- 33 km of Thompson River upstream of Pukaist Creek (about 4 km upstream of Ashcroft);
- 12 km of Nicola River upstream of Thompson River;
- 28 km of Fraser River upstream of Lytton; and
- 7 km of Coquihalla River upstream of Hope.

The study area is predominately located within the Thompson-Nicola region which ranges from semiarid desert-like terrain with rolling grasslands and meandering rivers to dense forests and white water rivers located in deep canyons. General descriptions of the rivers along the flood route are presented below.

Pukaist Creek has the steepest average grade (approximately 10%) of the entire flood route. The upstream portion of Pukaist Creek, immediately downstream of the L-L Dam, is located within a semi-arid pine forest. Further downstream the channel grade and the pine forest density reduce until the creek enters the Thompson River. The creek is located in a V-shaped valley with relatively steep sidewalls.

The upstream reach of the Thompson River within the study area, between Ashcroft and Spences Bridge, is located in a broad valley. The river meanders and is slightly incised as it continues to carve through a flatland plateau. As it moves downstream towards the Fraser River, more white water is apparent and broad valley becomes increasingly narrow. The banks along the Thompson River within the study area have very little vegetation within the riparian zone.

A major tributary of the Thompson River within the study area is the Nicola River. The Nicola River follows a meandering channel in a u-shaped valley. Sand and gravel banks and bars are present along the Nicola River with sparsely populated shrubs along these banks.



The Fraser River is roughly three times as wide as the Thompson River at the Thompson/Fraser confluence. The upstream portion of the Fraser River, near the confluence with the Thompson River, is located in a broad valley with a channel that slightly meanders. Further downstream, the river becomes increasingly incised and the vegetation density increases as the river exits the Fraser canyon at Yale. At Hope, the Fraser River enters a broad floodplain extending a distance of approximately 140 km to the coast.

Major populated areas within the study area include: the First Nation community at the confluence of the Nicola and Thompson Rivers, as well as the following towns/villages: Spences Bridge, Lytton, Boston Bar, Spuzzum, Yale, Hope and Laidlaw. In addition to these relatively denser populated areas there are also scattered farmlands along the Thompson, Nicola and Fraser Rivers.

Both the Thompson River and the Fraser River are major transportation corridors. Infrastructure within the study area includes roads, highways, railways, bridges, and power and gas transmission lines. Major highways downstream of the L-L Dam include (see Figure 2.1): the Trans-Canada Highway (Highway 1), the Nicola Highway (Highway 8), the Highland Valley Road (Highway 97C), the Lytton-Lillooet Highway (Highway 12), and the Lougheed Highway (Highway 7).

## 2.3 Concurrent River Flows

The naturally occurring flows in the creeks and rivers downstream of the dam were estimated from Water Survey of Canada (WSC) streamflow records for the Thompson, Fraser, and Coquihalla Rivers. Flows at key locations of interest between the WSC stream gauging stations were interpolated based on catchment area. These values are summarized in Table 2.1. The mean annual flows (MAFs) were based on the average daily values at the WSC gauging stations.

Flows for various return periods were estimated by frequency analysis of the WSC streamflow records using the Log Pearson distribution. The probable maximum floods (PMFs) presented in the table were based on the "Probable Maximum Flood Estimator for British Columbia" published by Agriculture and Agri-Foods Canada (AAFC, 2010).

The study area's river networks and stream gauge locations are shown in Figure 2.1.

**Table 2.1** Estimated Naturally Occurring Flows in the Rivers

WSC Station Number	Stream Gauging Station Name and/ or	Catchment Area	Flow (m <sup>3</sup> /s)				
wsc station Number	Location	(km²)	MAF	200-Year	PMF		
08LF051 and 08LF022	Thompson River at Spences Bridge	54,600	760	4,370	27,500		
-	Thompson River upstream of Lytton	56,800	800	-	28,200		
08MF005	Fraser River upstream of Texas Creek	154,000	1,730	8,170	51,500		
-	Fraser River upstream of Lytton	156,000	1,790	-	51,900		
-	Fraser River downstream of Boston Bar	214,500	2,640	-	62,900		
08MF068	Coquihalla River upstream of Alexander Creek	720	30	410	900		
08MF005	Fraser River at Hope	217,000	2,700	14,160	63,400		
-	Fraser River at Laidlaw	217,400	2,770	-	63,400		
08MF035	Fraser River near Agassiz	218,000	2,900	14,830	63,500		
08MH024	Fraser River at Mission	228,000	3,300	-	65,300		

Notes: WSC: Water Survey of Canada

PMF: Probable Maximum Flood (values estimated with the PMF Estimator for BC, which uses one hour instantaneous values).

MAF: Mean Annual Flow (mean annual flow and flood frequency analysis flows are based on daily average values).

#### 3 DAM SAFETY STANDARDS

The L-L Dam has been designed and constructed to meet or exceed the Dam Safety Guidelines published by the Canadian Dam Association in 2007 (CDA, 2007). The CDA guidelines outline criteria for the design of dams based on the downstream consequence classification of the structure. A summary of the 2007 CDA consequence categories and their established thresholds are shown in Table 3.1.

Table 3.1 2007 CDA Dam Safety Guidelines – Dam Classification Categories

	Population		Incremental Los	ses
Dam Class	at Risk (Note 1)	Potential for Loss of Life (Note 2)	Environmental and Cultural Values	Infrastructure and Economics
Extreme	Permanent	More than 100	Major loss of critical fish or wildlife habitat. Restoration or compensation in kind impossible.	Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances).
Very High	Permanent	100 or fewer	Significant loss or deterioration of critical fish or wildlife habitat. Restoration or compensation in kind possible but impractical.	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances).
High	Permanent	10 or fewer	Significant loss or deterioration of important fish or wildlife habitat. Restoration of compensation in kind highly possible.	High economic losses affecting infrastructure, public transportation, and commercial facilities.
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat. Loss of marginal habitat only. Restoration or compensation in kind highly possible.	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes.
Low	None	0	Minimal short-term loss No long-term loss.	Low economic losses; area contains limited infrastructure or services.

Note 1: Definition for population at risk:

**None** – There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

**Temporary** – People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

**Permanent** – The population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequences classes (High, Very High, Extreme) are proposed to allow for more detailed estimated of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2: Implications for loss of life:

**Unspecified** – The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

The CDA Dam Safety Guidelines indicate that the term "consequence" refers to the incremental damage above and beyond the damage that would have occurred in the same event or conditions had the dam not breached. These may also be called "incremental consequences" of a dam breach.

The L-L Dam was classified as Very High according to the 1999 CDA Dam Safety Guidelines, which is the highest dam classification in the 1999 guidelines (KCB, 2010). This dam classification was not formally reviewed to reflect the updated 2007 CDA Dam Safety Guidelines, which moved from a four to a five dam class scheme. However, based on criteria presented in the updated guidelines, a reclassification of the L-L Dam as Extreme was adopted for all design work for the dam since the 2007 guidelines were released. As it can be seen from Table 3.1, Extreme is the highest dam classification in the 2007 CDA guidelines. The seismic and flood design criteria suggested by the 2007 Dam Safety Guidelines for dams classified as Extreme, and the design criteria adopted for the L-L Dam, are shown in Table 3.2. The Highland TSF is operated as a closed system, where no surface water is released from the TSF to the environment. Therefore, the impoundment is provided with sufficient allowance to store the Inflow Design Flood until such time as the closure spillway is constructed.

Table 3.2 Selected Seismic and Flood Design Criteria for L-L Dam

Design Parameter	2007 Dam Safety Guidelines Design Criteria for Extreme Classifications	Selected Design Criteria for L-L Dam
Maximum Design Earthquake	10,000 year return period	10,000 year return period or Maximum Credible Earthquake
Inflow Design Flood (IDF)	Probable Max. Flood (PMF)	L-L Dam has an IDF for operation and an IDF for closure, as shown below
Inflow Design Flood — Operation	-	Provide flood storage allowance to store the larger of the following two inflow scenarios:  average annual runoff plus 100-year 24-hour flood plus inflows resulting from a 24-hour Probable Maximum Precipitation (PMP); or average annual snowmelt runoff plus inflows resulting from a 120-hour PMP.
Inflow Design Flood – Closure	-	Closure spillway sized to handle the PMF

#### 4 DAM BREACH METHODOLOGY AND ASSUMPTIONS

## 4.1 Hydraulic Model

#### 4.1.1 HEC-RAS Computer Model

The HEC-RAS model was used for the dam breach and inundation analyses for L-L Dam. HEC-RAS is a one-dimensional hydraulic model developed by the US Army Corps of Engineers (USACE). This model is widely used and is considered to be one of the industry standard models. The HEC-RAS model is capable of steady and unsteady flow simulations in river channels. The unsteady component of the model includes calculation of outflows resulting from a dam breach as well as routing of these flows along the channel downstream of the dam.

The HEC-GeoRAS software extension to HEC-RAS, available from the USACE was used for pre- and post-processing of the HEC-RAS data. HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface (GUI). The interface allows the preparation of geometric data such as channel cross-sections for importing into HEC-RAS, and it processes simulation results exported from HEC-RAS. HEC-GeoRAS was used to prepare the geometric data for input to the HEC-RAS model. Upon completion of the HEC-RAS runs, the HEC-RAS output was exported to HEC-GeoRAS for processing and delineation of flood limits.

#### 4.1.2 Model Geometry

The following digital topographic data was used for the study:

- 2 m resolution Digital Elevation Model (DEM) Data for Pukaist Creek, a section of the Thompson River that extends 18 km upstream of the Pukaist Creek and downstream about 12 km below Spences Bridge, and 12 km of the Nicola River upstream from the confluence with the Thompson River.
- 10 m horizontal and 5 m vertical resolution BC TRIM data was used for the remainder of the model described in Section 2.

Topography is input to HEC-RAS via the use of cross-sections drawn across the river. These cross-sections and their spacing along the river determine the geometric and hydraulic parameterization of the numerical model. Roughly 500 cross-sections were sampled across the model domain: about 100 sections were created with the DEM topography and about 400 sections were created with the BC TRIM data. Approximate locations of the cross-sections and extents of the different topography data are shown in Figure 4.1.

Dam breach modeling consists of rapidly varying flow and water levels. These large changes often result in numerical model instabilities. To increase stability the models must be refined. The following refinements were completed to increase the stability of the model:

• Interpolated cross-sections were inserted at 20 m spacing in Pukaist Creek. These interpolated cross-sections were required because the changes in flow and water level were the most

significant near the L-L Dam and because the slope of Pukaist Creek is much greater compared to the other rivers included in the model.

- Manning's roughness coefficients (n) were increased along Pukaist Creek and a portion of the Thompson River near the confluence with Pukaist Creek. These adjustments were required to stabilize the model. The base case scenarios were still run with the representative Manning's n. See Table 4.3 for a list of Manning's n used in the model.
- Only large tributaries were included in the model.

Because bathymetric data was not available for the rivers, the cross-sections were manually modified to contain the average annual river flows within the banks. It was assumed the DEM and TRIM data was obtained on a day with an average annual flow.

#### 4.1.3 Model Uncertainties

There are numerous uncertainties inherent in dam breach modelling and routing of extreme floods caused by a dam breach. Some of these are:

- Dam breach parameters The dam breach parameters, such as breach formation time, and breach depth, width and side slopes, are usually selected based on historical data and require a fair amount of judgment. Furthermore, most of the dams which have breached in the past have been small dams and the historical dam breach databases do not include high dams designed and constructed in compliance with modern standards, such as the L-L Dam.
- Tailings dam vs. water dams Most methodologies were developed based on a sample of breached water-retaining dams for which structural characteristics can be reasonably estimated. Tailings dams, however, often exhibit a poorly defined upstream face with uncertain structural characteristics.
- Lack of calibration of model Measured water level versus discharge data from a streamflow station is required to calibrate the model. Such data is often not available and, even if it is available, the data would cover only the range of flows recorded during the life of the station and not the extreme flood flows expected due a dam breach. Therefore, the model cannot be calibrated for extreme flood flows.
- Channel roughness coefficients Because the model cannot be calibrated, values of the Manning's roughness coefficient cannot be determined with certainty. Usually a best estimate of the channel roughness coefficient is used and a sensitivity analysis with various roughness values is carried out.

To quantify some of these uncertainties, sensitivity analyses were completed which varied the breach parameters and roughness coefficients. The base case and sensitivity analyses completed are summarized in Section 4.4.

#### 4.2 Dam Breach Scenarios

The following dam breach scenarios were assessed for the L-L Dam, which are consistent with the 2007 CDA Dam Safety Guidelines:

- Flood-induced dam breach:
  - Flood-induced dam breach is often referred to as a "rainy-day" breach. A rainy-day or
    overtopping type breach typically occurs during large flood inflow conditions where the
    pond water level rises high enough to breach or overtop the dam. The PMF was assumed
    as the concurrent flow in the river system for this breach scenario.
- Sunny-day dam breach (piping, earthquake):
  - Sunny-day breaches are normally assumed to occur when the pond is at its normal operating level. Examples of sunny day breaches include the slumping of the dam slope due to static or earthquake loading, or the breach of the dam caused by piping (internal erosion). The MAF was assumed as the concurrent flow in the river system for this breach scenario.

For the flood-induced (overtopping) scenario, the dam breach flood was combined with the PMF from the full river catchments. A PMF occurring in the watershed of all four rivers (i.e., Thompson, Nicola, Fraser and Coquihalla) at the same time is highly unlikely. A dam breach flood combined with a PMF from a partial catchment will indicate a larger incremental impact than that combined with a PMF from 100% of the catchment. However, because the dam is already designed for the highest dam classification in the CDA Dam Safety Guidelines (see Section 3), dam breach analysis with a PMF from a partial catchment to determine the dam classification is not necessary. Furthermore, the extent of flooding for a dam breach flood combined with a PMF from a partial catchment would be smaller than that combined with a PMF from 100% of the catchment. Therefore, the dam breach flood from the overtopping breach was combined with the PMF from the full catchment such that the worst case flood extents could be determined. The use of the PMF from 100% of the catchment provides the upper bound of the expected flooding and is a conservative approach for the formulation of the emergency preparedness and response plan.

The analyses presented herein are based on hypothetical dam breaches, and the results of such analyses in no way reflect upon the structural integrity or safety of the dam.

The dam heights and additional information on the dam breach scenarios considered for the rainy-day and sunny-day breaches are presented in Table 4.3.

## 4.3 Released Volumes

The Highland TSF is operated as a closed facility where, except for un-intercepted groundwater seepage from the impoundment, there is no discharge to the environment. The dam is raised annually ahead of the rising tailings level and the pond is provided with sufficient capacity to impound the upcoming year's tailings inflow, the required operating water volume plus a flood

storage allowance. The annual dam raise also includes a minimum 2 m freeboard above the estimated required tailings and water storage levels.

The operating water storage allowance is about 41 Mm<sup>3</sup>. The flood storage allowance is 49 Mm<sup>3</sup>, which is sufficient to store:

- an average annual runoff plus 100-year 24-hour flood plus inflows resulting from 24-hour Probable Maximum Precipitation (PMP); or
- an average annual snowmelt runoff plus inflows resulting from 120-hour PMP.

The TSF will ultimately impound approximately 1,545 Mm³ of tailings by year 2028. The recommended ultimate L-L Dam height at El. 1279 m includes the tailings impoundment allowance, operating water storage allowance, flood storage allowance, 2 m freeboard, and an approximate 1 m additional allowance for unknowns such as potential variations in tailings production, changes in water storage requirements, variations in tailings density and seismically induced crest displacements at the L-L Dam (KCB, 2010). Based on the configuration of tailings deposition by the end of operations and the various storage and freeboard allowances, the assumed tailings and water storage volumes for the dam breach analysis are shown in Table 4.1. For analyses of overtopping breaches, it is normal practice to allow between 0.3 m and 0.6 m of water depth above the dam crest in order to initiate the overtopping breach. As it can be seen from the Table 4.1, a 0.3 m overtopping depth was included in the analysis for the L-L Dam.

Table 4.1 Assumed Tailings and Water Storage Volumes for Dam Breach Analysis

	Sunny-day (Pip	ing) Dam Breach	Rainy-day (Overtop	ping) Dam Breach
Item	Tailings (Mm³)	Supernatant Water (Mm³)	Tailings (Mm³)	Supernatant Water (Mm³)
Tailings	1,545	-	1,545	-
Operating water	-	41	-	41
Flood water (Inflow Design Flood)	-	-	-	49
Water within 2 m freeboard plus 1 m extra allowance	-	-	-	45
Water within 0.3 m overtopping depth	-	-	-	6
TOTAL	1,545	41	1,545	141

NOTE: Supernatant water is the water above the tailings surface in the impoundment.

The volume of 141 Mm<sup>3</sup> of water used for the overtopping breach is based on the assumption that the pond has had sufficient inflow to fill up the operating water and the flood storage allowances, as well as the available 3 m freeboard. This volume also includes a 0.3 m depth of water above the dam crest to initiate the overtopping breach. Given the extreme inflow conditions assumed for the dam, an overtopping breach of the L-L Dam is considered to be a highly unlikely scenario. For example, for the L-L Dam to be overtopped, the flood inflow would have to be almost double the PMF volume which is an unlikely scenario.

The dam breach analyses completed for this study considered the release of free water and a portion of the tailings. Tailings impounded in tailings ponds have higher viscosity than water and, in the event

of a dam breach, usually not all the tailings are released from the impoundment. A review of databases of historical tailings dam breach data, taken from USCOLD (1995) and www.tailings.info, indicates that 1% to 100% of the tailings were released from the impoundments following a dam breach. The release proportion is dependent on the dam site and impoundment geometry, dam height, tailings storage volume, water pond volume, tailings characteristics and other factors. The historical data also indicates that, on average, 25% of the tailings were released. A recent article published by Azam and Li (2010), which examined data from 167 tailings dam breaches, indicates that the released tailings generally amount to approximately one-fifth (i.e., 20%) of the tailings contained within the facilities.

Analysis of potential releases of tailings from the impoundment behind the L-L Dam was carried out by taking into consideration the height of the dam, the height of the tailings in the impoundment, the configuration of the impoundment behind the dam, the angle of repose for the tailings, and physical tailings properties. The Highland TSF is a long, narrow, curved impoundment approximately 9.5 km long by 1.5 km to 3 km wide. Approximately 60% to 80% of the tailings will be spigotted into the impoundment from the H-H Dam, and the ultimate H-H Dam crest will be at El. 1292.7 (nominal) which is about 13.7 m higher than the L-L Dam. The supernatant pond will be located close to the L-L Dam. The volume of tailings released was estimated by assuming an angle of repose of 10H:1V (i.e., 5.7°), and all tailings above the breach bottom at this angle of repose was assumed to be released from the impoundment. This angle of repose was based on a tailings dam breach flow study by Lucia (1981), which listed final angles for various types of tailings inside and outside tailings impoundments. Based on these values, and in the event of a dam breach, the tailings behind L-L Dam are assumed to come to rest at approximately 10H:1V. Therefore, the estimated volume of tailings released from the impoundment depends on the breach bottom elevation, breach width and the geometry of the valley upstream of L-L Dam. Estimated volume of tailings released for various breach widths and breach bottom elevations are shown in Table 4.2 and, as the table indicates, the amount of tailings released ranges between 5% and 12% of the total tailings in the impoundment. Elevation 1146 m shown in the table as the breach bottom elevation is the elevation of the starter dam crest.

Table 4.2 Estimated Tailings Release Volumes

Breach Bottom Width (m)	Breach Bottom Elev. (m)	Tailings Storage Volume (Mm³)	Tailings Release Volume (Mm³)	Percentage of Impounded Tailings Released	Water Contained in Released Tailings (Mm³)
300	1146	1,545	154	10%	69
450	1146	1,545	180	12%	81
300	1180	1,545	82	5%	37
450	1180	1,545	98	6%	44

NOTE: Amount of water in tailings release volume is based on 30% moisture content by weight and an assumed tailings density of  $1.5 \text{ t/m}^3$ .

The volume of released tailings includes the tailings solids and water. A field investigation program was undertaken in March and April, 2013 to determine the properties of the tailings beach deposits upstream of the L-L Dam. Two test holes were drilled: one 78.9 m deep terminating at El. 1175.7 m; and the other 75.9 m deep terminating at El. 1179.1 m. The field investigation also included cone

penetration testing (CPT), standard penetration testing (SPT) and piston sampling in the beach deposits. The test results showed a dense zone of compacted cycloned sand (with a base at approximate El. 1220 m) overlying looser beach deposits. The loose beach deposits were identified as liquefiable, whereas the cycloned sand deposit was identified as not liquefiable. The loose deposit and the compacted cycloned sand zones are labelled as "tailings" and "cycloned sand fill" in Figure 2.2, respectively. Given that there is a loose beach deposit zone upstream of the dam and that the tailings deposits further upstream in the impoundment are likely to have similar characteristics, the tailings are expected to be released from the impoundment in the event of a dam breach.

Laboratory tests on the samples taken from the drill holes for the tailings beach investigation indicate that the beach deposits have an average moisture content of about 27% by weight. Laboratory tests also indicate that the samples contained mostly fine sand (smaller than 0.4 mm) and had an average fines content of about 25% (smaller than 0.075 mm). The estimated volumes of water in the released tailings, based on an assumed moisture content of 30% and a tailings dry density of  $1.5 \text{ t/m}^3$ , are shown in Table 4.2. As can be seen from the table, the water in the tailings constitutes about 45% of the total tailings release volume. For modeling purposes, the released tailings were assumed to behave (i.e., flow) like water. This is a conservative assumption because the tailings would be more viscous than water and would not flow as easily. Nevertheless, given the steep grade of Pukaist Creek (~ 10%) it is likely that the tailings would be transported by the flood wave to the Thompson River, which upon mixing with the water in the river would remain mobilized and potentially be transported downstream into the Fraser River.

#### 4.4 Dam Breach Parameters

Input parameters for simulating an overtopping dam breach in HEC-RAS include final breach bottom width, final breach bottom elevation, breach side slopes, breach formation time and weir discharge coefficient. The breach formation time is the time required for the breach in the dam to reach its specified final breach width and breach bottom level. Input parameters for simulating a piping breach include the parameters listed for an overtopping breach plus the initial piping elevation and the piping discharge coefficient. The breach parameters have to be estimated outside the HEC-RAS program, and they were estimated using regression equations and charts developed by researchers based on historical dam breach information. The various dam breach scenarios considered during this study and the corresponding dam breach parameters are presented in Table 4.3.

A breach formation time of 3.5 hours, and Manning's roughness coefficients of 0.035 in the main channel and 0.06 in the overbanks for the flood path, were selected as the base case scenario for both the piping and overtopping breaches. Sensitivity analyses with different breach formation times, roughness coefficients and initial piping elevation, as shown in Table 4.3, were also carried out.

Table 4.3 Dam Breach Parameters for Dam Breach Runs

		Overtopping Breach							Piping Breach												
Breach	Parameters	Tailings and Supernatant Water Released					pernatant	Tailings and Supernatant Water Released							Only Supernatant						
		Base Case			Sensitiv	ity Runs			Water F	Released	Base Case				Sensitivity	y Runs				Water Released	
Dam crest elevation (m)		1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279	1279
Width of the dam crest (	(m)	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Pond water elevation (m	1)	1279.3	1279.3	1279.3	1279.3	1279.3	1279.3	1279.3	1279.3	1279.3	1271	1271	1271	1271	1271	1271	1271	1271	1271	1271	1271
Volume of water release	ed (10 <sup>6</sup> m <sup>3</sup> )	141	141	141	141	141	141	141	141	141	41	41	41	41	41	41	41	41	41	41	41
Volume of tailings releas	sed (10 <sup>6</sup> m³)	109	109	109	109	109	109	109	0	0	179	179	179	179	179	179	179	179	179	0	0
Volume of water + tailin	gs released (10 <sup>6</sup> m³)	250	250	250	250	250	250	250	141	141	220	220	220	220	220	220	220	220	220	41	41
Final bottom breach wid	lth (m)	450	450	450	450	450	450	450	150	50	450	450	450	450	450	450	450	450	450	50	10
Final bottom breach ele	vation (m)	1180	1180	1180	1180	1180	1180	1180	1240	1220	1146	1146	1146	1146	1146	1146	1146	1146	1146	1240	1220
Breach side slopes		1.4H:1V	1.4H:1V	1.4H:1V	1.4H:1V	1.4H:1V	1.4H:1V	1.4H:1V	1.4H:1V	1.4H:1V	1.0H:V	1.0H:1V	1.0H:1V	1.0H:1V	1.0H:1V	1.0H:1V	1.0H:1V	1.0H:1V	1.0H:V	1.0H:1V	1.0H:1V
Breach weir discharge co	pefficient	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Breach formation time (	hours)	3.5	3.5	3.5	3.5	2.5	4.5	8.0	2.5	2.0	3.5	3.5	3.5	3.5	2.5	4.5	3.5	3.5	8.	2.0	2.0
Piping coefficient of disc	charge	-	-	-	-	-	-	-	-	-	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Initial piping elevation (r	n)	-	-	-	-	-	-	-	-	-	1208	1208	1208	1208	1208	1208	1178	1238	1208	1250	1230
Concurrent flow in river	downstream of dam	PMF	PMF	PMF	PMF	PMF	PMF	PMF	PMF	PMF	MAF	MAF	MAF	MAF	MAF	MAF	MAF	MAF	MAF	MAF	MAF
LL-Dam to Spences	Main Channel Manning's n	0.035	0.06	0.08	0.1	0.06 <sup>1</sup>	0.035	0.035	0.035	0.035	0.035	0.06	0.08	0.1	0.06 <sup>1</sup>	0.06 <sup>1</sup>	0.06 <sup>1</sup>	0.06 <sup>1</sup>	0.035	0.035	0.035
Bridge	Overbank Manning's n	0.06	0.06	0.08	0.1	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.1	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Spences Bridge to	Main Channel Manning's n	0.035	0.06	0.08	0.1	0.035	0.035	0.035	0.035	0.035	0.035	0.06	0.08	0.1	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Laidlaw	Overbank Manning's n	0.06	0.06	0.08	0.1	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.1	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Notes:

MAF: Mean Annual Flow

PMF: Probable Maximum Flood

<sup>1</sup>Manning's n was changed to 0.06 in the main channel for some of the sensitivity runs (vs. 0.035 for the Base Base) to improve numerical stability of the model.

One of the breach parameters which have to be defined for a piping type breach is the initial piping elevation. The results of the seismic response analyses for the ultimate L L Dam (El. 1279 m), which was completed in 2010 (KCB, 2010), were reviewed for the purpose of determining the most likely location of the initial pipe. The seismic response analyses had examined the pore-water pressure build-up and liquefaction triggering of the uncompacted tailings in the impoundment and, based on the results of the analyses, El. 1208 m was selected as the initial piping elevation for modelling the base case piping breach. Piping breaches based on other elevations were modelled to test the sensitivity to the initial pipe elevation.

The majority of the dam breach runs were made based on the assumption that both supernatant water and tailings are released from the impoundment. However, as Table 4.3 shows, two runs each were also made for the overtopping breach and the piping breach based on the assumption that only the supernatant water is released in order to ascertain the lower boundaries of potential consequences downstream of the dam. However, the results of the scenarios which assume both the water and the tailings are released, which are considered to be conservative and form the upper bound consequences, will be used for emergency preparedness and response planning purposes. Because only the water is assumed to be released, the selected breach bottom elevations for this scenario are higher and the breach bottom widths are smaller than those for the scenario where both the water and the tailings are assumed to be released.

HEC-RAS allows the formation of the breach through the dam embankment to be defined as a linear or a sinusoidal progression. The sinusoidal breach formation was selected for this study because it is believed to better represent the breaching processes.

## 5 MODEL RESULTS AND DISCUSSION

The following key locations along the flood route were selected for the presentation of the model results:

- in Pukaist Creek at the L-L Dam;
- in Pukaist Creek upstream of the confluence with the Thompson River;
- in the Thompson River at the confluence with the Nicola River;
- in the Thompson River near Ashcroft;
- in the Thompson River at Spences Bridge;
- in the Thompson River at Lytton, upstream of the confluence with the Fraser River;
- in the Fraser River at Boston Bar;
- in the Fraser River at Spuzzum;
- in the Fraser River at Yale;
- in the Fraser River at Hope; and
- in the Fraser River at Laidlaw.

Flood flow and stage (i.e., water depth) hydrographs for the locations listed above are presented Figure 5.1 to Figure 5.4 for the piping and overtopping breach base cases which assumed that both the supernatant water and the tailings are released from the impoundment. In addition to the base case, flood flow and stage hydrographs for the sensitivity runs are also presented in these figures. Similar charts for the scenario which assumes only the supernatant water is released are presented in Figure 5.16 and Figure 5.17.

Piping and overtopping breach flood inundation lines for the base case with the supernatant water and tailings released are presented in Figure 5.5, which has been divided into 16 sheets. Some of the flood flows for both the piping and the overtopping breaches of the L-L Dam are expected to spill into Coldstream Creek over the saddle between the Pukaist Creek and Coldstream Creek catchments located about 3 km downstream of the dam (see Figure 5.5, Sheet 3). The Coldstream channel was not included in the HEC-RAS model, but rough estimates of the flood limits along the channel are shown. Similar flood inundation maps for the scenario which assumes that only the supernatant water is released are presented in Figure 5.22, Sheets 1 to 15.

Additional discussion of the model results is presented in the following sub-sections.

## 5.1 Peak Flows

The flood hydrographs presented in Figure 5.1 and Figure 5.3 for piping and overtopping breaches, respectively, indicate that the peak discharge at the dam is sensitive to the breach formation time. The shorter the breach formation time, the larger the discharge. For example, the peak discharge at the dam for a piping breach initiated at El. 1208 m would be between 30,900 m $^3$ /s for an 8.0 hour breach formation time and 76,100 m $^3$ /s for a 2.5 hour breach formation time. The peak discharge at the dam for an overtopping breach would vary between 16,600 m $^3$ /s for an 8.0 hour breach formation time and 54,200 m $^3$ /s for a 2.5 hour breach formation time. In addition to the breach



formation time, the peak discharge for the piping breach is also influenced by the selection of the initial piping elevation. The lower the initial piping elevation, the higher the peak discharge.

Generally, floods resulting from a dam breach tend to attenuate due to valley storage and frictional resistance along the downstream reaches. This phenomenon is illustrated in Figures 5.1, 5.3, 5.6, 5.7, 5.16 and 5.18 which show a reduction in peak flows as the flood wave moves downstream along the flood route. For the breach at the L-L Dam, there is also backwatering and temporary retention of flood water in the tributary reaches such as the Thompson River upstream of Pukaist Creek, the Nicola River upstream of the Thompson River and the Fraser River upstream of the Thompson River. There is also backwatering in the Coquihalla River near Hope, but the amount is minimal because the dam breach flood is substantially attenuated by the time it reaches Hope. The abrupt changes in peak flows in Figures 5.6, 5.7 and 5.18 are either due to the reduction in the flow caused by the backwatering and retention of the flood water in the receiving stream or due to the addition of flow to the system by the receiving stream.

Peak flows for piping and overtopping breach base cases, with both water and tailings released from the impoundment, are summarized in Table 5.1. The peak flow shown for each location includes the concurrent flow in the river. The dam breach component of the peak flow (total peak flow minus concurrent flow) is also shown, along with the dam breach flow as a percentage of peak discharge at the dam. For both the piping and overtopping breaches, the majority of the flood attenuation is observed within the first 25 km of the flood route; the peak flow resulting from the dam breach is reduced to less than 50% by the time the flood reaches Spences Bridge. The peak flow resulting from the dam breach is reduced to about 30% at Lytton and to about 17% to 25% at Laidlaw. The estimated 200-year flows at selected locations on the Thompson and Fraser Rivers are shown in Table 5.1 for comparison purposes. The 200-year flood is the design standard for flood protection works in British Columbia. As the table shows, the dam breach flow at Hope and Laidlaw is either equal to or less than the 200-year flood.

Peak flows for selected piping and overtopping breaches for the case where only water is assumed to be released are summarized in Table 5.2. As expected, the peak discharges at the dam are smaller than those for the case where both the water and the tailings are assumed to be released (Table 5.1), and the dam breach discharges are attenuated with increasing distance from the dam.

Table 5.1 Peak Flows and Attenuation Summary - Water and Tailings Released

Location	Distance		Piping Breach	h - Base Cas	se	0	vertopping Brea	ach - Base Ca	se	Natural Flows (m <sup>3</sup> /s)		
	from L-L Dam (km)	Total Peak Flow (m³/s)	Concurrent Flow (m³/s)	Dam Breach Flow (m³/s)	Residual Dam Breach Flow	Total Peak Flow (m³/s)	Concurrent Flow (m³/s)	Dam Breach Flow (m³/s)	Residual Dam Breach Flow	200-yr (m³/s)	PMF (m³/s)	
L-L Dam	0	57,800	50	57,750	100%	38,900	300	38,600	99%	-	300	
Pukaist Ck. u/s of Thompson R.	11	43,100	50	43,050	74%	36,500	310	36,190	93%	-	310	
Thompson R. d/s of Pukaist Ck.	12	36,300	720	35,580	62%	49,000	19,710	29,290	75%	-	19,710	
Thompson R. d/s of Nicola R.	21	30,800	770	30,030	52%	48,500	27,510	20,990	54%	-	27,510	
Thompson R. at Spences Bridge	25	27,300	770	26,530	46%	45,700	27,510	18,190	47%	4,370	27,510	
Thompson R. u/s. of Fraser R.	60	20,500	800	19,700	34%	41,800	28,200	14,290	35%	-	28,200	
Fraser R. at Lytton	60	19,100	2,600	16,500	28%	75,000	62,900	12,100	31%	8,280	62,900	
Fraser R. at Boston Bar	103	16,900	2,640	14,260	25%	73,900	62,910	10,990	28%	14,200	62,910	
Fraser R. at Spuzzum	115	16,500	2,650	13,850	24%	73,700	62,920	10,780	28%	-	62,920	
Fraser R. at Yale	126	16,300	2,650	13,650	24%	73,600	62,920	10,680	27%	-	62,920	
Fraser R. at Hope	164	14,400	2,710	11,690	20%	73,200	63,400	9,800	25%	14,160	63,400	
Fraser R. at Laidlaw	184	12,500	2,770	9,730	17%	73,300	63,440	9,860	25%	14,200	63,440	

#### NOTES:

- 1. Concurrent flow for the piping breach scenario = Mean Annual Flow; concurrent flow for the overtopping breach scenario = Probable Maximum Flow.
- 2. Dam breach flow is the difference between total peak flow and concurrent flow.
- 3. Residual dam breach flow is dam breach flow given as a percentage of the peak flow at the dam.
- 4. The 200-year flow is taken from Table 2.1.

Table 5.2 Peak Flows and Attenuation Summary – Only Water Released

Location	Distanc e from	Piping Breach (BFT 2.0 hours, Breach El. 1220 m)				(BFT	Overtopping 2.5 hours, Brea		n)	Natural Flows		
	L-L Dam (km)	Total Peak Flow (m³/s)	Concurrent Flow (m³/s)	Dam Breach Flow (m³/s)	Residual Dam Breach Flow	Total Peak Flow (m³/s)	Concurrent Flow (m³/s)	Dam Breach Flow (m³/s)	Residual Dam Breach Flow	200-yr (m³/s)	PMF (m³/s)	
L-L Dam	0	7,930	50	7,880	100%	22,070	300	21,770	100%	-	300	
Pukaist Ck. u/s of Thompson R.	11	7,690	50	7,640	97%	21,390	310	21,080	97%	-	310	
Thompson R. d/s of Pukaist Ck.	12	7,790	720	7,070	90%	36,680	19,710	16,970	78%	-	19,710	
Thompson R. d/s of Nicola R.	21	7,250	770	6,480	82%	39,280	27,510	11,770	54%	-	27,510	
Thompson R. at Spences Bridge	25	6,870	770	6,100	77%	37,410	27,510	9,900	45%	4,370	27,510	
Thompson R. u/s. of Fraser R.	60	5,260	800	4,460	57%	35,070	28,200	6,870	32%	-	28,200	
Fraser R. at Lytton	60	6,600	2,600	4,000	51%	69,510	62,900	6,610	30%	8,280	62,900	
Fraser R. at Boston Bar	103	5,350	2,640	2,710	34%	69,000	62,910	6,090	28%	14,200	62,910	
Fraser R. at Spuzzum	115	5,290	2,650	2,640	33%	68,900	62,920	5,980	27%	-	62,920	
Fraser R. at Yale	126	5,200	2,650	2,550	32%	68,850	62,920	5,930	27%	-	62,920	
Fraser R. at Hope	164	4,690	2,710	1,980	25%	68,660	63,400	5,260	24%	14,160	63,400	
Fraser R. at Laidlaw	184	4,490	2,770	1,720	22%	68,930	63,440	5,490	25%	14,200	63,440	

#### NOTES:

- 1. Concurrent flow for the piping breach scenario = Mean Annual Flow; concurrent flow for the overtopping breach scenario = Probable Maximum Flow.
- 2. Dam breach flow is the difference between total peak flow and concurrent flow.
- 3. Residual dam breach flow is dam breach flow given as a percentage of the peak flow at the dam.
- 4. The 200-year flow is taken from Table 2.1.

## 5.2 Peak Water Levels

Figures 5.2, 5.4 and 5.17 show the water depth hydrographs at selected locations along the flood route for the piping and overtopping breaches. Plots of maximum water depths versus distance from L-L Dam are presented in Figures 5.10, 5.11 and 5.20. Figures 5.2 and 5.10 show the incremental rise in water level above the background MAF level, whereas Figure 5.4 and Figure 5.11 show the incremental rise in water level above the background PMF level for the case where the water and tailings are assumed to be released. Similar plots for the release of water only are presented in Figure 5.17 and Figure 5.20. The plots of the various sensitivity runs indicate that, although there is only a small difference in the maximum water level for the various runs, the rate of change for the rising and falling limbs of the stage hydrographs are sensitive to Manning's roughness coefficient. The larger the roughness coefficient, the slower the rise in water level and the longer it takes for the water level to drop to the level that was before the arrival of the flood.

For the scenario where water and tailings are released, the rise in water level for the piping breach ranges from approximately 25 m in the Thompson River near Spences Bridge to about 3 m above the MAF level in the Fraser River near Laidlaw. The rise in water level for the overtopping breach ranges from approximately 20 m in the Thompson River near Spences Bridge to about 1 m above the PMF level in the Fraser River near Laidlaw. The relatively small increases in water depths at Laidlaw indicate that the flood from a breach at the L-L Dam would be substantially attenuated by the time it reaches Laidlaw. Given that the breach flows at the dam for the scenario where only the water is released are smaller, the rise in water levels for this scenario is also smaller. For example, for the overtopping scenarios with the release of only water, the rise of the water level above PMF varies approximately between 10 m in in the Thompson River near Spences Bridge and 0.5 m in the Fraser River near Laidlaw.

## 5.3 Flood Arrival Time, Time to Peak and Flood Duration

Flood arrival time is the time it takes for the flood resulting from a dam breach to arrive at a particular location after the commencement of a breach at the dam. That is, it is the time when the water level in the river begins to rise. The time to peak is the time, after commencement of a breach at the dam, when the water level or discharge at a particular location reaches its maximum. Flood duration is the time from arrival of the flood to the time when the flow in the river returns to its original level. For the case where the water and tailings are assumed to be released the flood arrival time, time to peak and flood duration for piping and overtopping breach base cases, as well as for sensitivity analyses, can be ascertained from the flow and stage hydrographs presented in Figure 5.1 to Figure 5.4. These values for the piping and overtopping breach base cases are summarized in Table 5.3. For the case where the release of only water is assumed the flow and stage hydrographs are plotted in Figure 5.16 and Figure 5.17. The corresponding values for the flood arrival time, time to peak and flood duration for piping and overtopping breaches are presented in Table 5.4.

Plots of time to peak water level versus distance from L-L Dam are presented in Figures 5.12, 5.13 and 5.21 for ease of reference and emergency preparedness and response planning purposes.

Table 5.3 Dam Breach Flood Arrival Time, Time to Peak and Flood Duration - Water and Tailings Released

Location	Distance from L-L Dam (km)	Piping Bro	each Base Cas	e (hr:min)	Overtopping Breach Base Case (hr:min)		
		Arrival Time	Time To Peak	Duration	Arrival Time	Time To Peak	Duration
At L-L Dam	0	-	-	-	-	-	-
Pukaist Ck. at Thompson R.	11	0:40	1:40	7:20	0:50	2:20	6:00
Thompson R. at Nicola R.	21	1:10	2:50	11:30	1:00	3:40	17:30
Thompson R. at Spences Bridge	25	1:20	2:50	12:10	1:10	3:40	17:20
Fraser R. at Lytton	60	2:50	4:30	11:30	1:30	5:10	19:00
Fraser R. at Boston Bar	103	3:50	6:10	13:00	2:20	6:40	18:10
Fraser R. at Spuzzum	115	4:20	6:30	14:30	2:30	6:40	18:00
Fraser R. at Yale	126	4:50	7:00	15:30	2:40	7:00	17:50
Fraser R. at Hope	164	6:30	9:20	19:30	3:10	8:10	21:50
Fraser R. at Laidlaw	184	7:30	10:40	20:10	3:50	9:10	21:20

#### NOTES:

- 1. Flood arrival time and time to peak are time after start of dam breach.
- 2. Duration is the time from the arrival of flood to the time when the flow returns to the original flow in the river.

Table 5.4 Dam Breach Flood Arrival Time, Time to Peak and Flood Duration - Only Water Released

Location	Distance from L-L Dam (km)	Piping Breach (BFT 2.0 hours, Breach El. 1220 m)			Overtopping Breach (BFT 2.5 hours, Breach El. 1240 m)		
		Arrival Time	Time To Peak	Duration	Arrival Time	Time To Peak	Duration
At L-L Dam	0	-	-	-	-	-	-
Pukaist Ck. at Thompson R.	11	0:40	1:50	7:20	0:40	2:10	11:20
Thompson R. at Nicola R.	21	1:10	2:30	8:50	1:01	3:30	12:10
Thompson R. at Spences Bridge	25	1:30	2:50	9:30	1:10	3:40	12:00
Fraser R. at Lytton	60	3:10	4:30	10:00	1:35	5:25	14:35
Fraser R. at Boston Bar	103	4:40	7:10	12:50	2:16	6:45	15:55
Fraser R. at Spuzzum	115	5:10	7:40	14:00	2:30	6:50	14:30
Fraser R. at Yale	126	5:40	8:15	14:40	2:45	7:5	15:25
Fraser R. at Hope	164	7:10	11:10	16:30	3:20	8:15	16:50
Fraser R. at Laidlaw	184	8:40	12:50	17:00	4:10	9:15	16:40

#### NOTES:

- 1. Flood arrival time and time to peak are time after start of dam breach.
- 2. Duration is the time from the arrival of flood to the time when the flow returns to the original flow in the river.

The above noted figures and Table 5.3 indicate that the flood wave due to the release of water and tailings would move rapidly from L-L Dam to areas downstream of the dam. Average base case flood speeds from L-L Dam to Laidlaw are approximately 25 km/h and 48 km/h for the piping and overtopping breaches, respectively. The speed with which the flood wave propagates downstream appears to be a function of the selected breach formation time and the channel roughness coefficient. For the base case piping breach it takes about 1hr:20min, 2hr:50min and 6hr:30min for the front end of the flood wave to reach Spences Bridge, Lytton and Hope, respectively. For the base case overtopping breach it takes about 1hr:10min, 1hr:30min and 3hr:10min for the flood wave to reach Spences Bridge, Lytton and Hope, respectively. Depending on the type of dam breach, concurrent flow conditions in the river and location along the flood route, it would take approximately 1 hour to about 5 hours for the flood to peak after arrival of the front end of the flood wave. For the case where only water is released, the flood wave moves slightly slower (Table 5.4). The average flood velocity from L-L Dam to Laidlaw is approximately 20 km/h and 45 km/h for the piping and overtopping breaches, respectively.

The first major populated area downstream of the L-L Dam is Spences Bridge and, as the results presented in Table 5.3 and Table 5.4 indicate, the time available to issue warnings before the flood arrives at Spences Bridge is very short (about 1 hour to 1.5 hour). Available warning times increase as the distance from the dam increases.

The durations of the flood along the flood route downstream of the dam vary from about 6 hours to about 22 hours. Flood durations are shorter for areas close to the dam, and increase as the distance from the dam increases.

#### 5.4 Results in the Backwater Reaches

The results presented thus far have been for the flood route from L-L Dam to Laidlaw. In addition to evaluating the inundation along the flood route, flooding along major river tributaries was also evaluated. There are four large river junctions along the flood route downstream of the L-L Dam:

- in the Thompson River upstream of the confluence with Pukaist Creek;
- in the Nicola River, a tributary to the Thompson River upstream of Spences Bridge;
- in the Fraser River upstream of the confluence with the Thompson River (at Lytton); and
- in the Coquihalla River, a tributary to the Fraser River at the town of Hope.

Backwater lengths and flood depths in the backwater tributaries and rivers are summarized in Table 5.5 for the scenario where both the water and tailings are assumed to be released from the impoundment. Additional information such as peak flows and peak water levels as well as their respective time and duration can be interpreted from Figure 5.14 and Figure 5.15. As expected, backwater effects are greatest in the rivers closest to the L-L Dam.

Table 5.5 Summary of Inundation Lengths and Flood Depth from Backwatering - Water and Tailings Released

Backwater River Reach	Thompson River u/s of Pukaist Creek	Nicola River u/s of Thompson River	Fraser River u/s of Thompson River	Coquihalla River u/s of Fraser River				
Reach Length included in HEC-RAS Model (km)	33	12	28	7				
Overtopping Breach – Base Case								
Backwater Length (km)	22.5	6.6	>29 (Note 3)	2.2				
Breach Flood Depth (m)	23.7	19.4	4	1.3				
Piping Breach – Base case								
Backwater Length (km)	18.0	3.3	22	0.7				
Breach Flood Depth (m)	19.7	21.3	16	6.7				

#### NOTES:

- 1. Backwater Length is the inundation distance upstream from the confluence with the adjoining river or creek.
- 2. Flood depth is the flood depth at the confluence; it reduces to 0 m at the upstream extent of inundation.
- 3. The model includes 28 km of Fraser River upstream of the Fraser River/Thompson River confluence. The inundation depth at 28 km is 1.9 m, therefore inundation would extend further upstream than shown.

## 5.5 Sensitivity Analysis

## 5.5.1 Water and Tailings Released

Analyses were conducted to test the sensitivity of model results to model parameters such as Manning's roughness coefficient (n), breach formation time, and breach bottom width and elevation. For the piping breach, the initial piping elevation was also assessed. The sensitivity of the piping and overtopping breaches to Manning's roughness coefficient, breach formation time and initial piping elevation, for the case where both water and tailings are released, is illustrated in Figure 5.1 to Figure 5.4, and in Figure 5.6 to Figure 5.13. Sensitivity to Manning's n was assessed through simulations with n = 0.06, 0.08, 0.10 and 0.12, either with a uniform n value across the entire channel cross-section or with a main channel value of 0.035 and a higher value in the overbanks. The flows and flood depths along the upper reaches of the model were found to be not sensitive to changes in Manning's n, but become more sensitive with increasing distance from the dam. In general, an increased value of Manning's n:

- produced greater water depths overall for a set discharge;
- reduced wave velocity, resulting in a delayed flood arrival; and
- increased the attenuation of the flood wave as it moved further downstream, resulting in decreased peak water level and increased flood duration along the lower reaches of the model.

The model was run with breach formation times of 2.5 hours, 3.5 hours, 4.5 hours and 8.0 hours. The results were found to be very sensitive to the breach formation time along the upper reaches of the model. The sensitivity to breach formation time decreased with increasing distance from the dam,

and there was practically no difference in peak flows and flood depths by the time the flood wave reached Laidlaw.

Piping breach scenarios were run with initial piping elevations of 1178 m, 1208 m and 1238 m. The peak discharge at the dam was found to be very sensitive to the initial piping elevation. In general, lower piping elevations resulted in higher peak flows (see Table 5.6 and Figure 5.1). The sensitivity to the initial piping elevation decreased rapidly with increasing distance from the dam (Figure 5.6). The discharge of 57,800 m³/s at the dam for the base case piping breach (i.e., initial piping elevation = 1208 m) is much higher than the discharge of 38,900 m³/s for the base case overtopping breach (see Table 5.1). This appears to be primarily due to the selection of the initial piping elevation for the base case piping breach. An initial piping elevation of 1230 m would result in approximately the same discharge as that for the base case overtopping breach.

Table 5.6 Sensitivity to Initial Piping Elevation for Piping Breach - Water and Tailings Released

Breach Formation Time	Initial Piping Elev.	Final Beach Bottom Elev.	Peak Discharge at Dam
(hours)	(m)	(m)	(m³/s)
3.5	1238	1146	33,500
3.5	1208	1146	57,800
3.5	1178	1146	77,000

Sensitivity analysis for breach bottom width indicates that the discharge at the dam for overtopping breach is relatively insensitive to the selected breach bottom width. The estimated discharges were approximately  $38,600 \text{ m}^3/\text{s}$ ,  $38,500 \text{ m}^3/\text{s}$  and  $37,200 \text{ m}^3/\text{s}$  for breach bottom widths of 450 m, 250 m and 150 m. The discharges at the dam for piping breaches were found to be more sensitive, with resulting discharges of  $57,800 \text{ m}^3/\text{s}$ ,  $49,000 \text{ m}^3/\text{s}$  and  $43,000 \text{ m}^3/\text{s}$  for breach bottom widths of 450 m, 250 m and 150 m, respectively.

For the overtopping breach, this study assumed the PMF occurred over the entire contributing catchment, which represents the worst case scenario for the purpose of emergency preparedness and response planning. The 2012 dam breach and inundation study for L-L Dam (KCB, 2012b) considered the PMF values based on 50% of the Thompson River catchment. The inundation plots for 50% PMF, with and without the overtopping dam breach, from the 2012 study are presented in Appendix I for comparison purposes. The 2012 study covered the area up to about 12 km downstream of Spences Bridge. As expected, a comparison of Figures 5.5, Sheets 3, 4 and 5 with the figures presented in Appendix I indicate that the inundation extents for the 100% PMF, with and without the dam breach, are larger than those for the 50% PMF. Nevertheless, the plots also indicate that extensive flooding will occur at the community at the mouth of the Nicola River and in Spences Bridge for both the 50% PMF and 100% PMF regardless of whether or not there is a dam breach.

#### 5.5.2 Release of Water Only

For the case where only water is released from the dam, two scenarios were considered for each of the piping and overtopping breaches. For the piping breach, a scenario with breach bottom elevation of 1240 m, initial piping elevation of 1250 m and breach bottom width of 50 m was compared with a scenario with breach bottom elevation of 1220 m, initial piping elevation of 1230 m and breach

bottom width of 10 m. For both of these scenarios, the breach formation time was set to 2 hr. For the overtopping breach, a scenario with breach bottom elevation of 1240 m, breach bottom width of 150 m and breach formation time of 2.5 hr was compared with a scenario with breach bottom elevation of 1220 m, breach bottom width of 10 m and breach formation time of 3.0 hr. The sensitivity plots for these scenarios are presented in Figure 5.16 to Figure 5.21. As the results indicate, there is not a significant difference in the flood and stage hydrographs between the scenario with breach bottom elevation at 1240 m and the scenario with breach bottom elevation at 1220 m for both piping and overtopping breaches. Generally, everything else being equal, the lower breach bottom elevation is expected to result in a larger peak discharge and this is the case for the two piping breach scenarios modelled. However, this is not the case for the overtopping breach because different breach formation times were selected for the two overtopping scenarios. Nevertheless, by the time the flood reaches Lytton, the stage and flood hydrographs for the two piping breach scenarios and the two overtopping breach scenarios are almost identical.

# 5.6 Potential Impacts within Inundation Areas

The following flood inundation maps are included in this report:

- Figure 5.5 shows the estimated flood lines for the base case piping breach and the base case overtopping breach where both the supernatant water and a portion of the impounded tailings are assumed to be released.
- Figure 5.22 shows the estimated flood lines for the piping and overtopping breaches where only the supernatant water is assumed to be released.

The high resolution imagery used for the upper reaches of the flood maps was provided by Teck HVC, and the ESRI GIS on-line satellite imagery was used for the rest of the flood maps. Three inundation extents are shown in Figure 5.5 and Figure 5.22, representing:

- the piping breach of L-L Dam combined with the MAF in the rivers;
- the overtopping breach of L-L Dam combined with the PMF in the rivers; and
- the PMF in the rivers without a dam breach.

No inundation extents are shown for the MAF without a dam breach, however it is assumed that the extents for the MAF without a dam breach would be confined within the river's main channel. Incremental flooding for a piping breach would be determined by comparing the piping dam breach inundation extents to the MAF without a dam breach, therefore comparison should be made to the river's outline. Incremental flooding for overtopping breach would be determined by comparing the overtopping dam breach inundation extents to the PMF, therefore comparison should be made to the inundation extents for the PMF without a dam breach. The scope of this study does not include potential geotechnical issues resulting from a surge in river water levels. The description of impacts presented herein is limited to impacts due to flooding only.

Estimates of number of dwellings affected and population present in the inundation zone, and railways, highways, water wells and surface water licences that could be affected, are presented in Table 5.7 and Table 5.8. The results from the worst case scenario (i.e., both water and tailings are released) have been used for this assessment. Population present in the inundation zone is not a count of loss of life. Loss of life could be equal to or less than the population. Please refer to the notes at the bottom of the tables for explanation of how the values presented in the tables were derived. Potential impacts for the dam breach scenarios with the release of only water would be less than those indicated in these tables.

Starting from L-L Dam, the following observations are made based on the river reach segments presented in Table 5.7 and Table 5.8. Left and right directions are based on looking downstream along the river.

Table 5.7 Population and Structures Affected – Base Case Piping Breach - Water and Tailings Released

River Reach	River Reach	Dam Breach or	Flood Depth	No. of Dwellings	Population in	No. of Highway and Railway Bridges		Length of Ra	ilway or Hi (km)	ghway Flo	oded		No. of Water	No. of Water
RIVEL REACTI	Length (km)	Discharge Scenario	(m)	Flooded	Inundation Zone	Affected	Railway (left bank)	Railway (right bank)	Hwy. 1	Hwy. 8	Hwy. 7	Hwy. 5	Wells Affected	Licences Affected
		Piping Breach	15 to 65	0	0	2	0	0	0	0	0	0	5	2
On Pukaist Creek from L-L Dam to Thompson River	11.2	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
mompson tuve.		Incremental Impact	-	0	0	2	0	0	0	0	0	0	5	2
		Piping Breach	0 to 5	0	0	0	7	9.5	0	0	0	0	8	13
On Thompson River from Pukaist  Creek to Ashcroft	36	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
Creek to your ore		Incremental Impact	-	0	0	0	7	9.5	0	0	0	0	8	13
		Piping Breach	5 to 25	3	7	0	10	10	0.5	0	0	0	1	2
On Thompson River from Pukaist Creek to Nicola River	9.7	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
Creek to Nicola River		Incremental Impact	-	3	7	0	10	10	0.5	0	0	0	1	2
		Piping Breach	0 to 25	26	60	2	0	0	0	1	0	0	8	7
On Nicola River upstream of Thompson River	11.6	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
mompson river		Incremental Impact		26	60	2	0	0	0	1	0	0	8	7
	1.2	Piping Breach	30 to 35	75	165	2	1	1	1	1	0	0	0	1
On Thompson River at Spences Bridge		MAF only	-	0	0	0	0	0	0	0	0	0	0	0
		Incremental Impact	-	75	165	2	1	1	1	1	0	0	0	1
On Thompson River from Spences Bridge to Lytton		Piping Breach	20 to 30	1	2	2	10	16	14	0	0	0	2	7
	34	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
		Incremental Impact		1	2	2	10	16	14	0	0	0	2	7
		Piping Breach	5 to 20	0	0	River Ferry and Pedestrian Bridge	0	0	0	0	0	0	0	0
On Fraser River upstream of Lytton	9	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
, ,		Incremental Impact	-	0	0	River Ferry and Pedestrian Bridge	0	0	0	0	0	0	0	0
		Piping Breach	10 to 20	0	0	1	0	0	0	0	0	0	1	0
On Fraser River at Lytton	4	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
		Incremental Impact		0	0	1	0	0	0	0	0	0	1	0
		Piping Breach	10 to 20	1	2	3	7	12	0	0	0	0	0	4
On Fraser River from Lytton up to and	46	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
including Boston Bar		Incremental Impact	-	1	2	3	7	12	0	0	0	0	0	4
		Piping Breach	10 to 20	0	0	Hells Gate and Alexandra bridges	4	8	<1	0	0	0	1	0
On Fraser River from Boston Bar up to	28	MAF only		0	0	0	0	0	0	0	0	0	0	0
and including Spuzzum		Incremental Impact		0	0	Hells Gate and Alexandra bridges	4	8	<1	0	0	0	1	0
		Piping Breach	10 to 20	0	0	0	2.4	8	<1	0	0	0	0	2
On Fraser River from Spuzzum up to and including Yale	16	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
		Incremental Impact		0	0	0	2.4	8	<1	0	0	0	0	2
		Piping Breach	10 to 20	0	0	0	1	10	0.1	0	0	0	0	1
On Fraser River from Yale to	18	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
upstream of Hope		Incremental Impact	-	0	0	0	1	10	0.1	0	0	0	0	1

River Reach	River Reach	Dam Breach or	Flood Depth	No. of	Population in	No. of Highway and Railway Bridges		Length of Ra	ilway or Hi (km)	ighway Flo	oded	No. of Water	No. of Water	
	Length (km)	Discharge Scenario	(m)	Dwellings Flooded	Inundation Zone	Affected	Railway (left bank)	Railway (right bank)	Hwy. 1	Hwy. 8	Hwy. 7	Hwy. 5	Wells Affected	Licences Affected
On Fraser River at Hope	4.8	Piping Breach	5	25	58	1	0	0	0	0	0	0	2	6
		MAF only	-	0	0	0	0	0	0	0	0	0	0	0
		Incremental Impact	-	25	58	1	0	0	0	0	0	0	2	6
On the Fraser River from Hope up to and including Laidlaw		Piping Breach	0 to 10	10	23	0	14	6	6	0	10	0	148	11
	15.2	MAF only	-	0	0	0	0	0	0	0	0	0	0	0
		Incremental Impact	-	10	23	0	14	6	6	0	10	0	148	11

- 1. All values in the table are approximate.
- 2. To determine incremental impact of a piping breach, the value given for "MAF only" was deducted from the value given for "piping breach".
- 3. Flood depth ranges are based on water depths above the channel invert.
- 4. The number of dwellings, bridges and roads impacted were counted by overlaying the flood inundation lines on GoogleEarth<sup>TM</sup> satellite imagery.
- 5. The population in the inundation zone was based on an assumption of 2.2 people per dwelling, and the total was rounded to nearest one person.
- 6. At Hope, the population in the inundation zone was based on the 2011 census data.
- 7. Population counts do not include people present within the inundation zone on a temporary basis, such as those taking part in recreational activities in the rivers, camping on the river banks, or travelling along the highways, railways and local roads.
- 8. Water wells and water licences were based on information in IMapBC. The majority of the water users are for extraction for agriculture and/or domestic use.

Table 5.8 Population and Structures Affected – Base Case Overtopping Breach - Water and Tailings Released

River Reach	River Reach Length	Dam Breach or	Flood Depth	No. of Dwellings	Population in	No. of Highway and Railway Bridges		Length of Rai	lway or Hig (km)	ghway Flo	oded		No. of Water	No. of Water
	(km)	Discharge Scenario	(m)	Flooded	Inundation Zone	Affected	Railway (left bank)	Railway (right bank)	Hwy. 1	Hwy. 8	Hwy. 7	Hwy. 5	Wells Affected	Licences Affected
		Overtopping Breach	15 to 55	0	0	2	0	0	0	0	0	0	5	2
On Pukaist Creek from L-L Dam to Thompson River	11.2	PMF only	5 to 25	0	0	2	0	0	0	0	0	0	4	2
mempsen niver		Incremental Impact	10 to 30	0	0	0	0	0	0	0	0	0	1	0
a = 1		Overtopping Breach	10 to 35	11	25	3	17	13	5	0	0	0	10	13
On Thompson River from Pukaist  Creek to Ashcroft	36	PMF only	0 to 10	0	0	3	16	13	0	0	0	0	9	13
Greek to / Isrier or t		Incremental Impact	10 to 25	11	25	0	1	0	5	0	0	0	1	0
		Overtopping Breach	35 to 55	3	7	0	10	10	2	0	0	0	1	2
On Thompson River from Pukaist Creek to Nicola River	9.7	PMF only	15 to 35	3	7	0	9	10	0.2	0	0	0	1	2
Creek to Micola River		Incremental Impact	20	0	0	0	1	0	1.8	0	0	0	0	0
		Overtopping Breach	10 to 70	37	85	4	0	0	0	12	0	0	13	7
On Nicola River upstream of Thompson River	11.6	PMF only	10 to 30	34	78	4	0	0	0	11	0	0	11	7
Thompson tivel		Incremental Impact	0 to 40	3	7	0	0	0	0	1	0	0	2	0
		Overtopping Breach	50 to 70	81	178	2	1	1	1	1	0	0	1	1
On Thompson River at Spences Bridge	1.2	PMF only	30 to 45	78	172	2	1	1	1	1	0	0	1	1
		Incremental Impact	20 to 25	3	6	0	0	0	0	0	0	0	0	0
On Thompson River from Spences Bridge to Lytton		Overtopping Breach	25 to 45	1	2	2	18	26	22	0	0	0	5	8
	34	PMF only	20 to 40	1	2	2	12	23	16	0	0	0	4	7
		Incremental Impact	5	0	0	0	6	3	6	0	0	0	1	1
On Fraser River upstream of Lytton		Overtopping Breach	25 to 45	5	11	River Ferry and Pedestrian Bridge	0	0	0	0	0	0	1	1
	9	PMF only	20 to 40	5	11	River Ferry and Pedestrian Bridge	0	0	0	0	0	0	1	1
		Incremental Impact	5	0	0	0	0	0	0	0	0	0	0	0
		Overtopping Breach	45	1	2	1	0	1	0	0	0	0	0	0
On Fraser River at Lytton	4	PMF only	40	0	0	1	0	1	0	0	0	0	0	0
		Incremental Impact	5	1	2	0	0	0	0	0	0	0	0	0
		Overtopping Breach	35 to 45	1	2	3	8	24	0	0	0	0	0	4
On Fraser River from Lytton up to and including Boston Bar	46	PMF only	25 to 30	0	0	3	7	20	0	0	0	0	0	4
including boston bar		Incremental Impact	10 to 15	1	0	0	1	4	0	0	0	0	0	0
On Fraser River from Boston Bar up to and including Spuzzum		Overtopping Breach	35 to 45	0	0	Hells Gate and Alexandra bridges	13	22	<1	0	0	0	2	0
	28	PMF only	30 to 35	0	0	Hells Gate and Alexandra bridges	10	20	<1	0	0	0	2	0
		Incremental Impact	5 to 10	0	0	0	3	2	0	0	0	0	0	0
On Fraser River from Spuzzum up to and including Yale		Overtopping Breach	30 to 40	50	115	0	14	16	11	0	0	0	1	4
	16	PMF only	25 to 35	40	92	0	12	14	10	0	0	0	1	4
		Incremental Impact	5	10	23	0	2	2	1	0	0	0	0	0
		Overtopping Breach	25 to 30	55	127	0	10	18	3	0	0	0	21	4
On Fraser River from Yale to	18	PMF only	15 to 20	45	104	0	10	18	2	0	0	0	21	4
upstream of Hope		Incremental Impact	10	10	23	0	0	0	1	0	0	0	0	0

River Reach	River Reach	Dam Breach or	Flood Depth	No. of	Population in	No. of Highway and Railway Bridges		Length of Ra	ilway or Hi (km)	ighway Flo	oded		No. of Water	No. of Water
	Length (km)	Discharge Scenario	(m)	Dwellings Flooded	Inundation Zone	Affected	Railway (left bank)	Railway (right bank)	Hwy. 1	Hwy. 8	Hwy. 7	Hwy. 5	Wells Affected	Licences Affected
On Fraser River at Hope		Overtopping Breach	25 to 30	1,680	3,600	1	0	5	0	0	0	0	6	7
	4.8	PMF only	25 to 30	1,620	3,500	1	0	5	0	0	0	0	6	7
		Incremental Impact	0	60	100	0	0	0	0	0	0	0	0	0
On the Fraser River from Hope up to and including Laidlaw		Overtopping Breach	10 to 15	120	276	0	20	15	14	0	14	1	174	14
	15.2	PMF only	10 to 15	120	276	0	20	15	14	0	14	1	170	14
		Incremental Impact	0	0	0	0	0	0	0	0	0	0	4	0

- 1. All values in the table are approximate.
- 2. To determine incremental impact of an overtopping breach, the value given for "PMF only" was deducted from the value given for "overtopping breach".
- 3. Flood depth ranges are based on water depths above the channel invert.
- 4. The number of dwellings, bridges and roads impacted were counted by overlaying the flood inundation lines on GoogleEarth<sup>TM</sup> satellite imagery.
- 5. The population in the inundation zone was based on an assumption of 2.2 people per dwelling, and the total was rounded to nearest one person.
- 6. At Hope, the population in the inundation zone was based on the 2011 census data.
- 7. Population counts do not include people present within the inundation zone on a temporary basis, such as those taking part in recreational activities in the rivers, camping on the river banks, or travelling along the highways, railways and local roads.
- 8. Water wells and water licences were based on information in IMapBC. The majority of the water users are for extraction for agriculture and/or domestic use.

#### On Pukaist Creek from L-L Dam to Thompson River:

- The flood inundation extents for piping and overtopping breaches are almost the same along Pukaist Creek due to the narrow creek valley with steep side slopes. Nevertheless, inundation extents for both breach scenarios are much wider than the estimated inundation limits for the MAF and the PMF (without the dam breach). There is a farm on the south bank of Pukaist Creek near its confluence with the Thompson River. The farm is on high ground and is not expected to be affected. The railway bridge and local road crossings on Pukaist Creek would be washed out. Although there is no permanent population within the flood zone, there could be potential loss of life if someone was in the area when the flood wave passes through.
- The floods from both piping and overtopping breaches are expected to overflow from Pukaist Creek into Coldstream Creek, as shown in Figure 5.5, Sheet 3. The flood flow in Coldstream Creek could potentially split into two routes just before entering the Thompson River as shown in the figure. Local road crossings and the railway embankment on Coldstream Creek would be washed out. Although there is no permanent population within the flood zone, there could be potential loss of life if someone was in the area when the flood wave passes through.

### On Thompson River from Pukaist Creek to Ashcroft:

- As indicated in Table 5.5, the flood from the piping breach would backwater into the Thompson River for a distance of about 18 km upstream of Pukaist Creek. Similarly, the flood from the overtopping breach would backwater for a distance of about 22.5 km. In both breach scenarios, the backwater effects of the flood would not reach Ashcroft.
- A piping breach of the dam is not expected to affect Highway 1, but substantial sections of the railways on both sides of the Thompson River will be flooded (see Table 5.7).
- The area near Teck HVC's Spatsum Pump Station (on the Thompson River about 6 km upstream of Pukaist/Thompson confluence) and small sections of the local road on the east side of the Thompson River will also be flooded.
- An overtopping breach of the dam is expected to flood about 4.6 km of Highway 1 (see Table 5.8). Approximately 17 km and 13 km of the railways on the left and right sides of the Thompson River, respectively, will also be flooded but, as it can be seen from Table 5.8, substantial sections of the railways would already be flooded by the PMF without a dam breach. Although there is no permanent population within the flood zone, there could be potential loss of life from people passing through the inundation area.

# On Thompson River from Pukaist Creek to Nicola River:

- The area along the Thompson River between Pukaist Creek and Nicola River has a few farms.
   Otherwise, the area is unpopulated. Highway 1, the two railways and local roads traverse the area.
- A piping type breach of L-L Dam would affect about 3 farms and about 10 km of the railways on both sides of the river. A short section of Highway 1 would also be affected (see Table 5.7).

An overtopping breach of L-L Dam would affect about 3 farms and about 10 km of the railways on both sides of the river. About 2 km of Highway 1 would also be affected. However, as Table 5.8 shows, the incremental impact of an overtopping breach is relatively small compared to the impact from a naturally occurring PMF without a dam breach.

### On Nicola River upstream of Thompson River:

- As indicated in Table 5.5, the flood from the piping breach would backwater into the Nicola River for a distance of about 3.3 km upstream of Thompson River. Similarly, the flood from the overtopping breach would backwater for a distance of about 6.6 km.
- There are a large number of dwellings and other structures at the mouth of the Nicola River.
   Additional dwellings, primarily consisting of farm houses, are located on both sides of the
   Nicola River further upstream. Other potential impacted structures along the Nicola River
   include Highway 8.
- In the event of a piping breach, only the dwellings at the mouth of the Nicola River and a short section of Highway 8 would be inundated. The population affected in the event of a piping breach would include those residing in the dwellings at the mouth of the river as well as anyone travelling along the relatively short section of flooded Highway 8.
- Wide spread flooding of dwellings and Highway 8 along the Nicola River is expected to occur
  under naturally occurring PMF as well as under an overtopping breach however, as it can be
  seen from Table 5.8, the impact of an overtopping breach of the dam over and above the
  natural PMF is relatively small.

#### On Thompson River at Spences Bridge:

• The town of Spences Bridge is located along the Thompson River approximately 1 km downstream of Nicola River. In the event of a naturally occurring PMF, a piping breach, or an overtopping breach, the majority of the town and transportation networks including railroads, roads, and bridges would be inundated. The incremental impact resulting from an overtopping breach over and above the PMF is small (Table 5.8), while the incremental impact resulting from a piping breach over and above the MAF is relatively large (Table 5.7).

### On Thompson River from Spences Bridge to Lytton:

- The area between Spences Bridge and Lytton is sparsely populated, and includes a few farms, fruit stands and the Goldpan Provincial Park camp ground. Sections of the Thompson River along this reach are also used for rafting and kayaking. Highway 1 follows the left bank of the river, and railways are located on both banks.
- Given that the area is sparsely populated, the permanent population within the inundation zone is small. However, as Table 5.7, Table 5.8 and Figure 5.5 indicate, substantial portions of the highway and the railways will be inundated under both the piping and overtopping breach scenarios as well as the PMF without a dam breach. The railway and Highway 12 bridges across the Thompson River at Lytton will also be flooded. Comparison of the dam breach flood

with naturally occurring floods indicates that the incremental impact of an overtopping breach is small, while the incremental impact a piping breach is relatively large.

### On Fraser River upstream of Lytton:

- Except for the low-lying area immediately upstream of Lytton, there are no dwellings or farms within the flood inundation zones along the Fraser River valley upstream of Lytton. A small reaction ferry, carrying passengers and vehicles across the Fraser River, is located about 1.6 km upstream of Lytton. There is also a pedestrian suspension bridge across the river approximately 6 km upstream of Lytton.
- As indicated in Table 5.5, the flood from the piping breach would backwater into the Fraser River for a distance of approximately 22 km upstream of the confluence with Thompson River. Similarly, the flood from the overtopping breach would backwater for a distance greater than 29 km. In both breach scenarios, incremental impacts over and above the naturally occurring floods are limited to a slight increase in inundation extent. A piping breach would impact the river ferry and the pedestrian suspension bridge. An overtopping breach would inundate some dwellings and affect the river ferry and the suspension bridge, but these impacts would be similar to a PMF event without a dam breach, therefore incremental impacts of an overtopping breach would be considered negligible.

### On Fraser River at Lytton:

The town of Lytton is located on high ground above steep river banks at the confluence of the Thompson and Fraser Rivers. Highway 1 and the two railways pass through the town on the left bank of the Fraser River. Except for the railway bridge across the Fraser River at the south end of the town, no other structures are expected to be flooded under a piping breach scenario. Approximately 1 km of one of the railways will be flooded under PMF without a dam breach. Impact due to an overtopping breach would be the same as the PMF without a dam breach plus flooding of one dwelling.

### On Fraser River from Lytton up to and including Boston Bar:

- Most of the Fraser River between Lytton and Boston Bar flows through an incised channel with steep banks, and there do not appear to be any farms within the potential flood zones. There are four communities along the river downstream of Lytton, which could be regarded as located close to the flood zones: Kanaka Bar, Canyon Alpine, North Bend and Boston Bar. Highway 1 is located on the left (east) side of the river, and there are railway tracks on both sides of the river. Two railway bridges cross the river about 9 km downstream of Lytton (near Kanaka Bar), and a road bridge crosses the river near Boston Bar. The Fraser River is used for whitewater rafting between Lytton and Yale.
- The dwellings in the four communities mentioned above (Kanaka Bar, Canyon Alpine, North Bend and Boston Bar) are located high enough to be not affected by a piping breach, the PMF or an overtopping breach. There appears to be one dwelling on the left (east) bank of the Fraser River about 4 km downstream of Kanaka Bar which could be flooded by a piping

- breach. This dwelling would also be flooded under the PMF without a dam breach, as well as under an overtopping breach.
- Approximately 7 km of the railway on the left bank and 12 km of railway on the right bank, and the three bridges mentioned above will be flooded under a piping breach (see Table 5.7).
   Additional sections of the railways will be flooded under the PMF and under overtopping breach as shown in Table 5.8.

# On Fraser River from Boston Bar up to and including Spuzzum:

- The river flows through the narrow Fraser Canyon between Boston Bar and Spuzzum. There are railway tracks on both sides of the river. Highway 1 is located on the left (east) side of the river between Boston Bar and Spuzzum, and then it crosses to the right (west) side at Spuzzum. Other crossings across the river include: the Hells Gate airtram and suspension bridge located about 12 km upstream of Spuzzum, and the historic Alexandra Bridge located about 2 km upstream of Spuzzum. There are also fish ladders on both sides of the Fraser River at Hells Gate. Hells Gate and the Alexander Bridge are popular tourist attractions, and the two bridges are open to public pedestrian traffic. At Hells Gate, the airtram takes tourists from the Highway 1 level down to a level just above the river on the other side. Facilities across the river include viewing decks, a restaurant, gift shop, display centre and other structures. There appear to be no dwellings along the Fraser River between Boston Bar and Spuzzum.
- The following structures would be affected by a piping breach at the L-L Dam: the bridge at Hells Gate; the Alexandra Bridge; about 4 km of railway on the left bank of the river; about 8 km of railway on the right bank and less than 1 km of Highway 1.
- The bridge at Hells Gate, the Alexandra Bridge and additional sections of the railways and Highway 1 will be flooded under the PMF and under overtopping breach however, as Table 5.8 shows, the incremental impact of overtopping breach over and above the PMF is small. The viewing decks and some of the buildings at Hells Gate would also be flooded under the PMF and under overtopping breach.
- The town of Spuzzum and the Highway 1 bridge at Spuzzum are high enough to be not affected by any flood scenario.

## On Fraser River from Spuzzum up to and including Yale:

- The Fraser River continues through the narrow Fraser Canyon between Spuzzum and Yale. There are railway tracks on both sides of the river. Highway 1 is located on the right (west) side of the river between Spuzzum and Yale. BC Hydro's Spuzzum sub-station is located on the right bank of the Fraser River at the Spuzzum Creek / Fraser River confluence just downstream of Spuzzum. Power transmission lines cross the Fraser River at the sub-station.
- Under a piping breach, approximately 2.4 km and 8 km of railway on the left and right banks of the Fraser River, respectively, and a short section of Highway 1 would be flooded. No dwellings are expected to be flooded.

- Under an overtopping breach, approximately 14 km and 16 km of railway on the left and right banks of the Fraser River, respectively, and 11 km of Highway 1 would be flooded. About 50 homes in the Yale area would be flooded (see Figure 5.5, Sheets 13 and 14). The railway and highway segments and the number of homes flooded under a PMF are slightly less than the overtopping breach, as shown in Table 5.8.
- The entire Spuzzum sub-station would be flooded under an overtopping breach. A much smaller section of the sub-station would be flooded under the PMF without a dam breach.

### On Fraser River between Yale and Hope:

- The Fraser River exits the Fraser Canyon at Yale and the valley begins to open up. There are railway tracks on both sides of the river. Highway 1 is located on the right (west) side of the river between Yale and Hope. There are several farms and settlements on the low-lying areas along the river between Yale and Hope, particularly on the right side of the river.
- Under a piping breach, approximately 1 km and 10 km of railway on the left and right banks of the Fraser River, respectively, and about 0.1 km of Highway 1 would be flooded. No dwellings are expected to be flooded.
- Under an overtopping breach, approximately 10 km and 18 km of railway on the left and right banks of the Fraser River, respectively, and 3 km of Highway 1 would be flooded. About 55 homes would also be flooded (see Figure 5.5, Sheets 13 to 15). The railway and highway segments and the number of homes flooded under PMF without a dam breach is slightly less than the overtopping breach, as shown in Table 5.8.

#### On Fraser River at Hope:

- The town of Hope is located on a floodplain at the confluence of the Coquihalla and Fraser Rivers. Highway 1 crosses over from the right side to the left side of the Fraser River at Hope.
- Inundation mapping indicates that approximately 25 homes, most of them located along the banks of the Fraser and Coquihalla Rivers, will be flooded under a piping breach. Given that the town is located on a floodplain and the BC TRIM topographic data with 5 m vertical resolution has been used for this area of the inundation model, there is some uncertainty in the extent of flooding indicated by the model. The total estimated peak flow at Hope for a piping breach is about 14,400 m³/s (see Table 5.1), which is almost the same as the estimated 200-year flow in the Fraser River at Hope (Table 2.1). The flood protection standard for British Columbia is the 200-year flood and, if the residential/commercial developments in Hope meet this requirement, the extent of flooding under piping breach could potentially be less than that indicated in Figure 5.5 (Sheet 15) and Table 5.7.
- A large portion of the town of Hope is expected to be flooded under an overtopping breach however, as Figure 5.5, Sheet 15 shows, the extent of flooding over and above the natural PMF is relatively small. The uncertainty in the extent of flooding indicated above for piping breach also applies to the PMF and the overtopping breach.

## On Fraser River from Hope up to and including Laidlaw:

- The Fraser River enters a broad floodplain at Hope, and Laidlaw is located on the floodplain. The area between Hope and Laidlaw is primarily agricultural, but there are few concentrations of residential areas on both sides of the river. Highway 1 is located on the left bank of the Fraser River and Highway 7 follows the right bank. There are railway tracks on both sides of the river. The Hope Regional Airpark is located on the left bank downstream of Hope.
- Inundation mapping for a piping breach (Figure 5.5, Sheets 15 and 16) indicates that low-lying areas between Hope and Laidlaw will be flooded but, as indicated above for flooding in the Hope area, there is some uncertainty in the extent of flooding because the area is very flat and the vertical resolution of the topographic data used is in the order of 5 m.
- The entire floodplain between Hope and Laidlaw is expected to be flooded under an overtopping breach however, as Figure 5.5, Sheets 15 and 16 show, the extent of flooding over and above the natural PMF is negligible. The inundation extents for the overtopping breach are almost the same as the inundation extents for the PMF. The uncertainty in the extent of flooding indicated above for piping breach also applies to the PMF and the overtopping breach.

### 5.7 Dam Classification

As mentioned in Section 3, a dam classification of Extreme as was adopted for the L-L Dam when the new (2007) Dam Safety Guidelines were released. This section presents a review of the dam classification based on the results of this dam breach and inundation study. The results from the worst case scenario (i.e., both water and tailings are released) have been used for the purpose of dam classification.

A comparison of inundation extents with and without the dam breach in Figure 5.5, and population and structures in the inundation zones with and without the dam breach in Table 5.7 and Table 5.8 indicate that the largest incremental impact due to a breach of the L-L Dam is expected to occur under the sunny-day breach scenario. This is because the magnitude of the flood released from the dam is much larger than the assumed naturally occurring flows in the rivers concurrent with the sunny-day dam breach. The incremental impact of a rainy-day (overtopping) breach of the L-L Dam is much smaller because there would be widespread flooding and damage under naturally occurring PMF without a dam breach.

The total permanent population in the inundation zone, from L-L Dam to Laidlaw, for the sunny-day breach is approximately 320. About 70% of this population (i.e., 230) is located in the Spences Bridge area, and the majority of the remaining population is in the Hope and Laidlaw area. These population counts do not include people present within the flood zone on a temporary basis, such as those taking part in recreational activities in the rivers, camping on the river banks or travelling along the highways, railways and local roads. Spences Bridge is relatively close to the dam, where the flood would arrive in less than 1.5 hour and it would peak in about 3 hours after the start of a breach at the dam. This might not provide adequate time to issue a warning and evacuate everyone out of the area. The flood arrival time and time to peak at Hope would be approximately 6.5 hours and

9.3 hours, respectively, which would probably provide sufficient time to issue a warning and evacuate people out of the flood zone. Given the short flood travel times from L-L Dam to Spences Bridge, assuming a fatality rate of between 25% and 50% would result in a potential loss of life of between 55 and 110 in the Spences Bridge area. According to the Dam Safety Guidelines (see Table 3.1) a dam with a potential loss of life of 100 or fewer would be classified as Very High, and a dam with a potential loss of life of more than 100 would be classified as Extreme. Therefore, the lowest classification for L-L Dam in terms of potential loss of life would be Very High, and the highest classification would be Extreme. The Extreme classification is selected for the purpose of this assessment.

Detailed assessment of potential environmental and cultural losses have not been carried out, however the Thompson and Fraser Rivers are known to be major fisheries migration routes of national importance, and the rivers are also used for First Nations food and recreational fishing. The release of flood waters and tailings into these watercourses, and the deposition of the tailings in the river channel and overbank areas as the flood recedes, is expected to cause major loss of critical fish habitat. Wildlife habitat along the flood route would also be affected. Therefore, the L-L Dam is classified as Extreme in terms of environmental losses.

The Thompson and Fraser Rivers within the study area are major transportation corridors which carry the Trans-Canada Highway, and two national railways (Canadian Pacific Railway and Canadian National Railway). The highway and the two railways are considered to be critical infrastructure not just for the British Columbia economy but the nation as a whole. As it can be seen from Figure 5.5, Table 5.7 and Table 5.8, the highway and railways will be flooded at a number of locations along the flood route. Some of the highway and railway sections might also be washed out and it might take some time before service can be restored. The loss of fish habitat and the potential for affecting salmon runs would cause extreme economic losses for many years following the dam breach incident. The flooding and deposition of tailings on agricultural lands would also result in economic losses. Therefore, the L-L Dam is classified as Extreme in terms of infrastructure and economic losses.

In conclusion, the L-L Dam is classified as Extreme in terms of loss of life, and environmental, infrastructure and economic losses. The overall classification of L-L Dam is Extreme, which agrees with the classification adopted for the design of the dam after the 2007 Dam Safety Guidelines were released. Loss of cultural values have not been assessed but, because the dam is classified as Extreme which is the highest dam classification possible, assessment of cultural values would not change the overall dam classification.

#### 6 CONCLUSIONS AND RECOMMENDATIONS

The dam breach and inundation analyses completed for the L-L Dam are based on hypothetical breach modes under extreme or highly unlikely conditions. The results of the dam breach and inundation analyses will be used to update the existing EPRP for the dam. Therefore, very conservative dam breach and inundation parameters have been used for this study in order to ascertain the worst case conditions with respect to EPRP. As such, some of the dam breach and inundation scenarios presented in this report are considered to be highly unlikely to occur. For example, for the L-L Dam to be overtopped, not only would the flood storage capacity in the tailings pond have to be used up, but the freeboard would also have to be occupied. Another example is the addition of the PMF from the full catchment of the receiving waters to the dam breach flows to prepare the flood inundation maps. The use of the full catchment PMF results in much larger inundation areas than what would be reasonably expected.

The results of this study indicate that a sunny-day or piping breach of the L-L Dam could have significant incremental downstream impacts. Sections of railways and roads adjacent to the Thompson and Fraser Rivers would be inundated; and many houses and other buildings in the communities and farmlands downstream would also be flooded. The incremental impacts of a rainy-day or overtopping breach, occurring at the same time as PMF conditions in the rivers downstream of the dam, are considered to be moderate because the areas subjected to flooding with the dam breach would experience widespread flooding under the naturally occurring PMF conditions without a dam breach.

Results of the model indicate that the flood wave would move relatively quickly downstream. For the case where water and tailings is released, for the base case piping breach it takes about 1hr:20min, 2hr:50min and 6hr:30min for the front end of the flood wave to reach Spences Bridge, Lytton and Hope, respectively. For the base case overtopping breach it takes about 1hr:10min, 1hr:30min and 3hr:10min for the flood wave to reach Spences Bridge, Lytton and Hope, respectively. The flood arrival time for the above mentioned locations, for the case where only water is released, is about 1hr:30 min, 3hr:10min and 7hr:10min for the piping breach, and is about 1hr:10min, 1hr:35min and 3hr:20min for the overtopping breach. Depending on the type of dam breach, concurrent flow conditions in the river and location along the flood route, it would take approximately 1 hour to about 5 hours for the flood to peak after the arrival of the front end of the flood wave.

For the case with the release of tailings and water the incremental flood water depths above the MAF would range between 28 m and 5 m for a piping breach, and that above the PMF would range between 20 m and 1 m for an overtopping breach. For the case with the release of only water the incremental flood water depths above the MAF would range between 8 m and 1 m for a piping breach, and that above the PMF would range between 10 m and 0.5 m for an overtopping breach.

For the case where tailings and water are released, the results for both the piping and overtopping breaches indicate that the peak flows resulting from the dam breach are reduced to less than 50% of the original discharge at the dam by the time the flood reaches Spences Bridge. The peak flows resulting from the dam breach are reduced to about 30% at Lytton and to about 17% to 25% at



Laidlaw. The dam breach flows at Hope and Laidlaw are either equal to or less than the estimated 200-year natural flood flow in the Fraser River. The 200-year flood is the design standard for flood protection works in British Columbia. Similar flood attenuation rates prevail for the overtopping case with the release of only water, however the piping breach achieved slightly lower rates of attenuation.

The results indicated that the breach flows with the release of only water for both overtopping and piping breaches are considerably smaller compared to those for the case where both the both tailings and water are assumed to be released. The peak flows at the dam for the case where only the water is released are about 15% to 30% of the flows for the case where tailings and water are released. For the piping breach, there is a significant difference in the extent of the inundated areas between the case with the release of tailings and water and the case with the release of only water. However, for the overtopping breach, the inundated areas for both of the cases are almost identical. This is because the majority of the flood volume in overtopping breaches comes from the PMF itself.

The results from the worst case scenario (i.e., both water and tailings are released) have been used for the purpose of classification of the L-L Dam and assessment of potential flood hazards. The risk of loss of life, particularly under a sunny-day breach scenario, could be high because it might not be possible to issue an advanced warning of impending flood in a timely manner to people potentially under threat. For a rainy-day (overtopping) breach, it is presumed that routine monitoring of the TSF would note the rising water level in the pond such that sufficient warning could be issued. Furthermore, given the large catchment of the Thompson River and the network of streamflow stations, including real-time monitoring stations, a flood warning related to the naturally occurring flood in the river is likely to be issued by the BC River Forecast Centre in a timely manner.

For the case where tailings and water is released, this study considered the release of only a portion of the tailings from the impoundment in addition to the free water. Given that the impoundment is a long, narrow facility, it was estimated that approximately 10% of the tailings would be released as a result of a breach. The flow of these tailings into the downstream rivers could potentially lead to significant environmental and economic impacts. Depending on the river flow conditions, some of the tailings would continue to travel further downstream and some of the tailings would be deposited on floodplains and riverbanks as the flood recedes, which could lead to significant environmental and economic impacts.

A dam classification of Extreme was adopted for the L-L Dam when the 2007 CDA Dam Safety Guidelines were released. Based on the results of this dam breach and inundation study, the L-L Dam is classified as Extreme in terms of loss of life, and environmental, infrastructure and economic losses. The overall classification of L-L Dam is Extreme, which agrees with the classification that was adopted in 2007. No design update for the L-L Dam is required because it is already designed, constructed and operated under that classification to the most stringent standards outlined in the Canadian Dam Safety Guidelines.

Given that this study is based on hypothetical dam breaches, the results of the analyses presented herein in no way reflect upon the structural integrity or safety of the dam.

This report is an instrument of service of Klohn Crippen Berger Ltd. The report has been prepared for the exclusive use of Teck Highland Valley Copper Partnership for the specific application to the Highland Tailings Storage Facility. The report's contents may not be relied upon by any other party without the express written permission of Klohn Crippen Berger. In this report, Klohn Crippen Berger has endeavoured to comply with generally-accepted professional practice common to the local area. Klohn Crippen Berger makes no warranty, express or implied.

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Yours truly,

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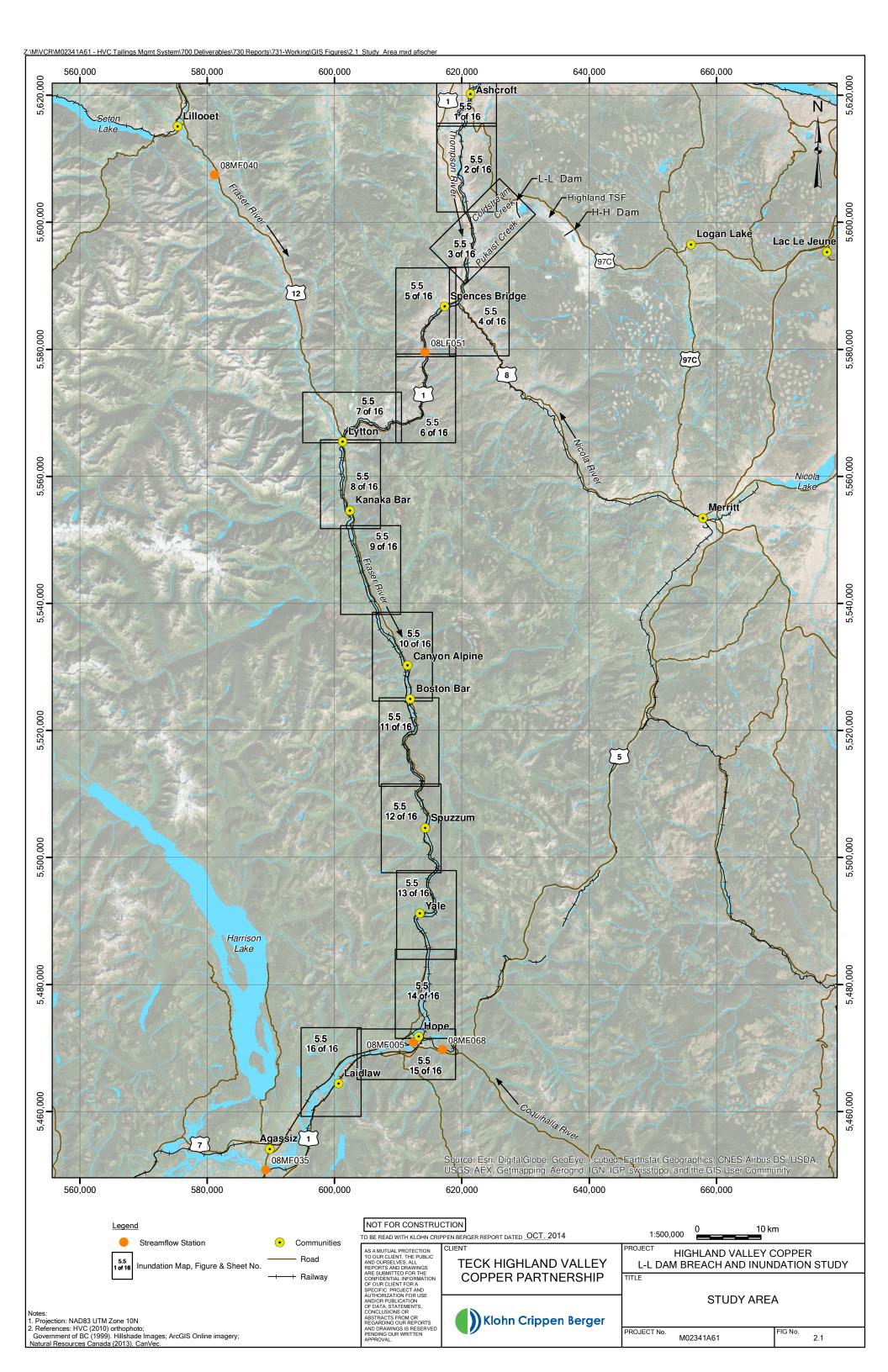
**Project Manager** 

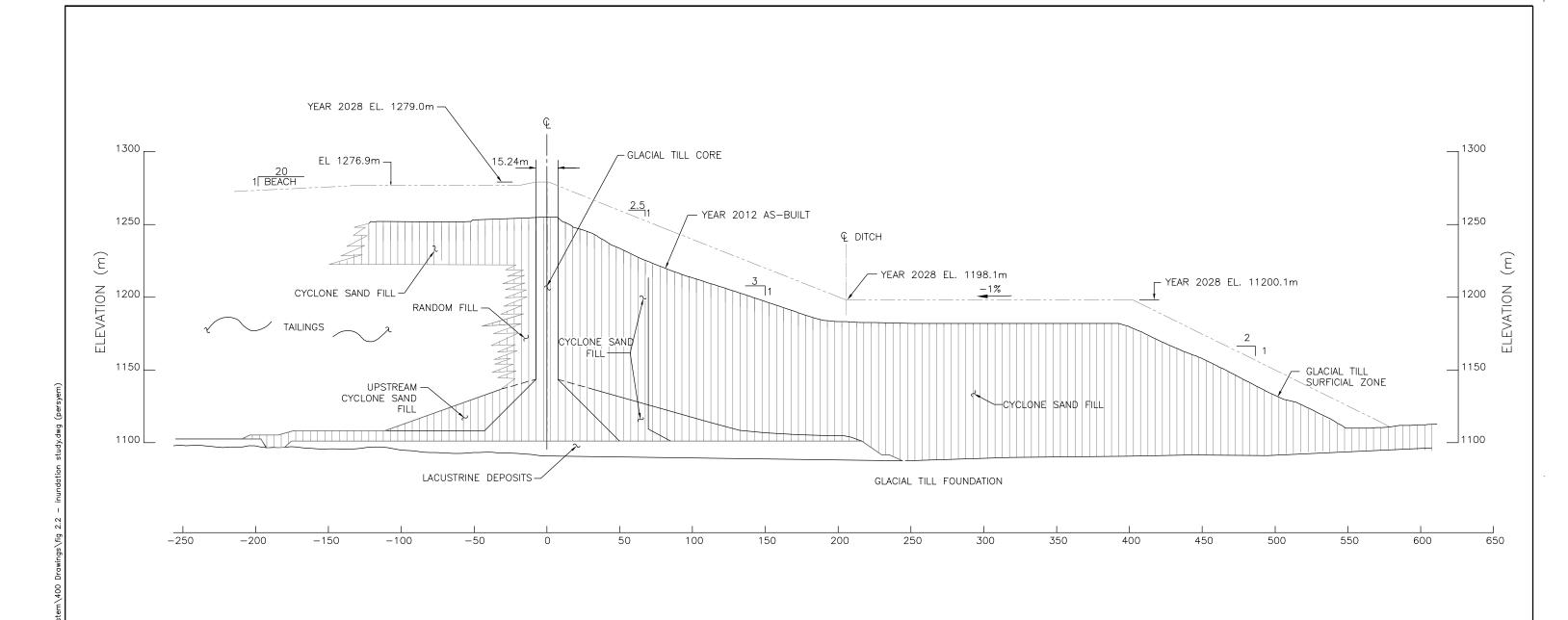
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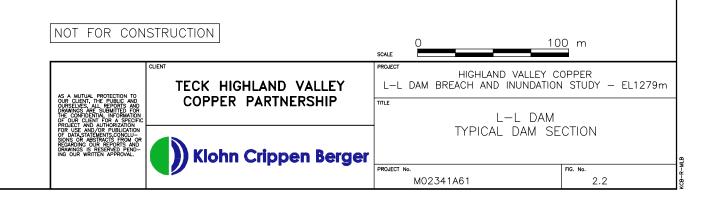
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# TYPICAL MID-VALLEY SECTION



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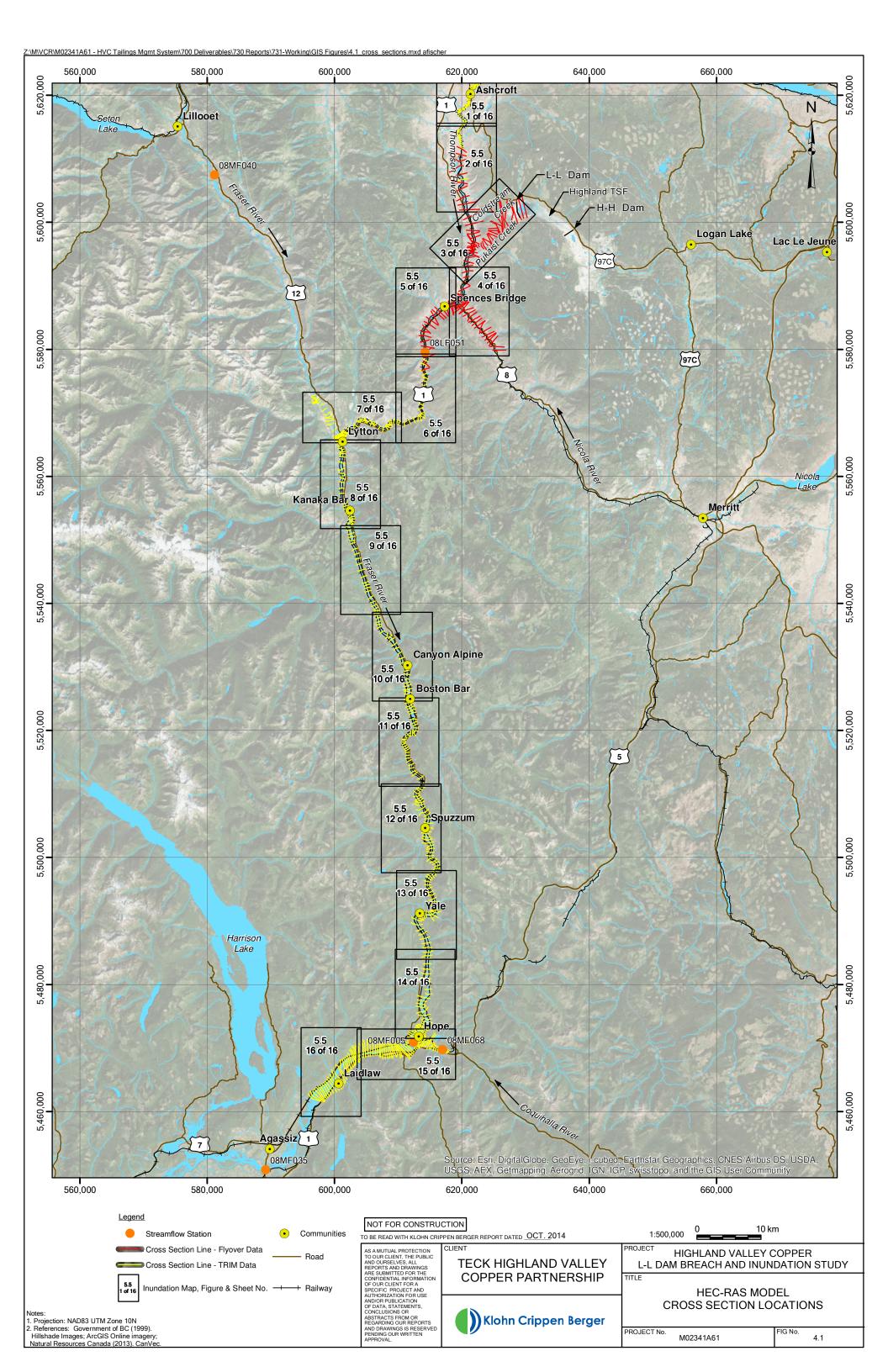
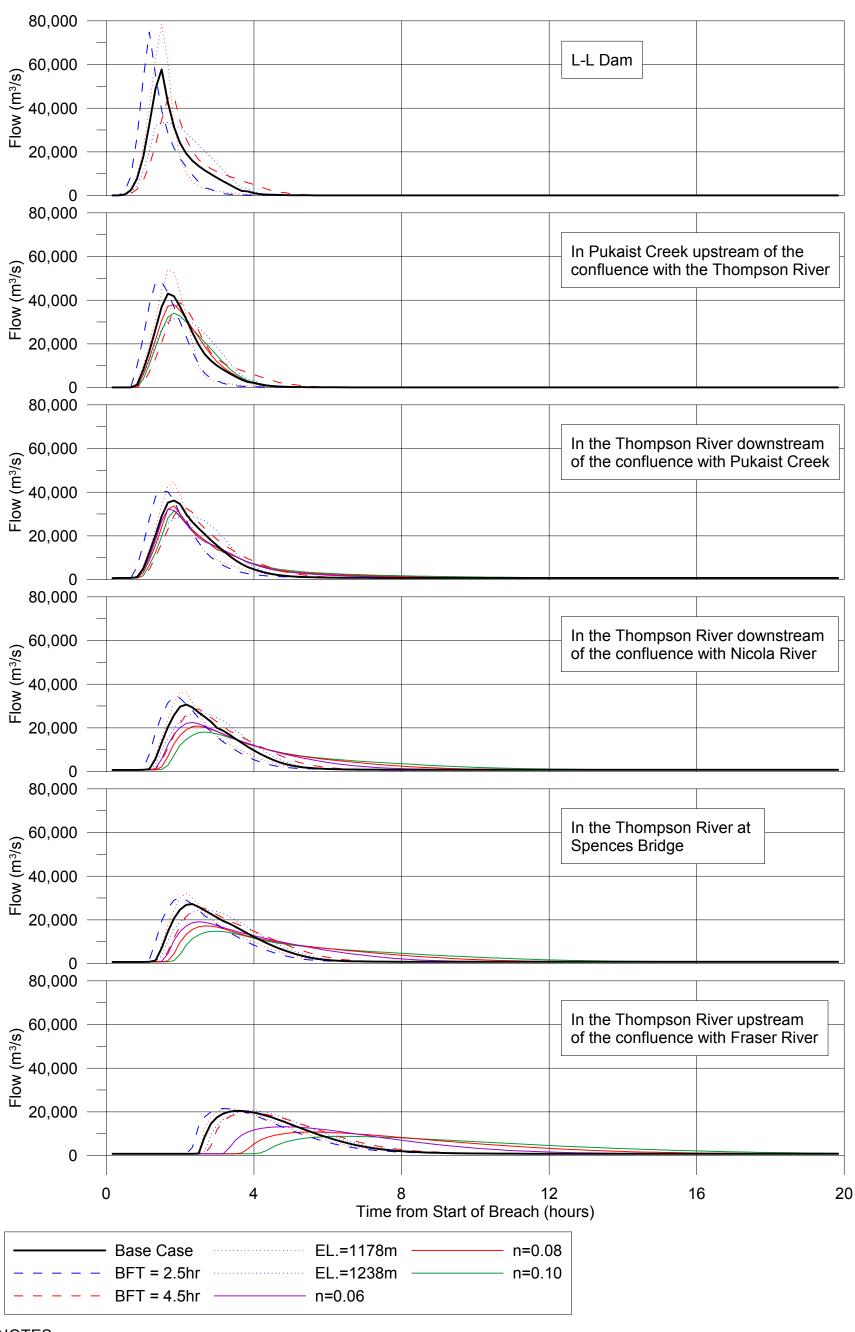


Figure 5.1 Piping Breach, Water and Tailings Released - Sensitivity Analyses - Flood Hydrographs (1 of 2)



2. Includes concurrent flow in rivers downstream of dam = Mean Annual Flow.

<sup>1.</sup> Base Case defined as Manning's n = 0.06 in the overbanks and 0.035 in the main channel. Breach Formation Time (BFT) = 3.5 hours. Initial piping elevation (EL.) = 1208 m.

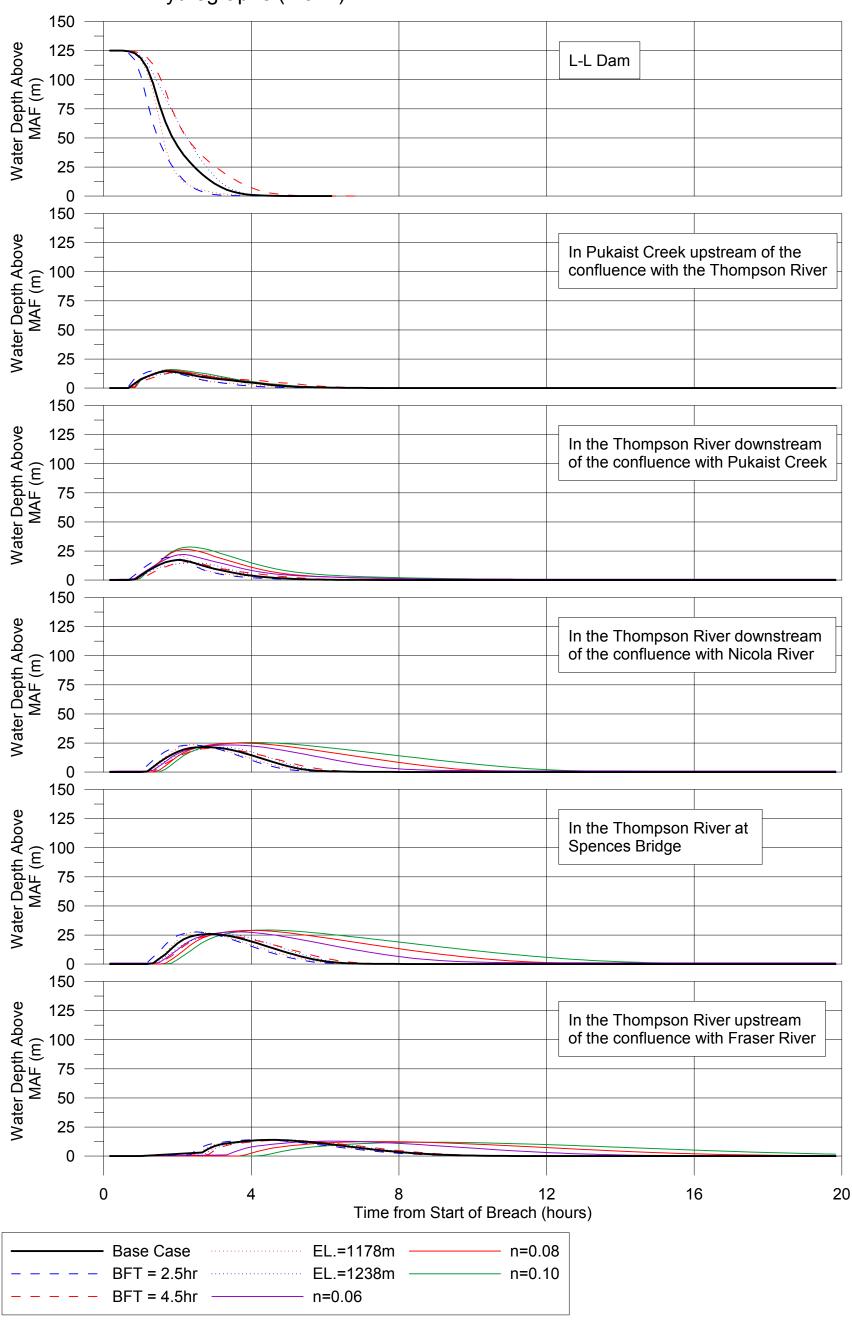
Hydrographs (2 of 2) 80,000 In the Fraser River downstream 60,000 (S/<sub>E</sub> ) 40,000 40,000 20,000 of the Thompson River (at Lytton) 20,000 0 80,000 In the Fraser River at Boston Bar 60,000 (S/<sub>E</sub> ) 40,000 40,000 20,000 20,000 0 80,000 In the Fraser River at Spuzzum 60,000 (S/<sub>E</sub> ) 40,000 40,000 20,000 20,000 0 80,000 In the Fraser River at Yale 60,000 (S/<sub>E</sub> 40,000 NOIL 20,000 20,000 0 80,000 In the Fraser River at Hope 60,000 (S/<sub>E</sub>H) 40,000 40,000 20,000 20,000 80,000 In the Fraser River at Laidlaw 60,000  $(m^3/s)$ 20,000 12 16 20 Time from Start of Breach (hours) EL.=1178m - Base Case - n=0.08— n=0.10 BFT = 4.5hr —

Figure 5.1 Piping Breach, Water and Tailings Released - Sensitivity Analyses - Flood

2. Includes concurrent flow in rivers downstream of dam = Mean Annual Flow.

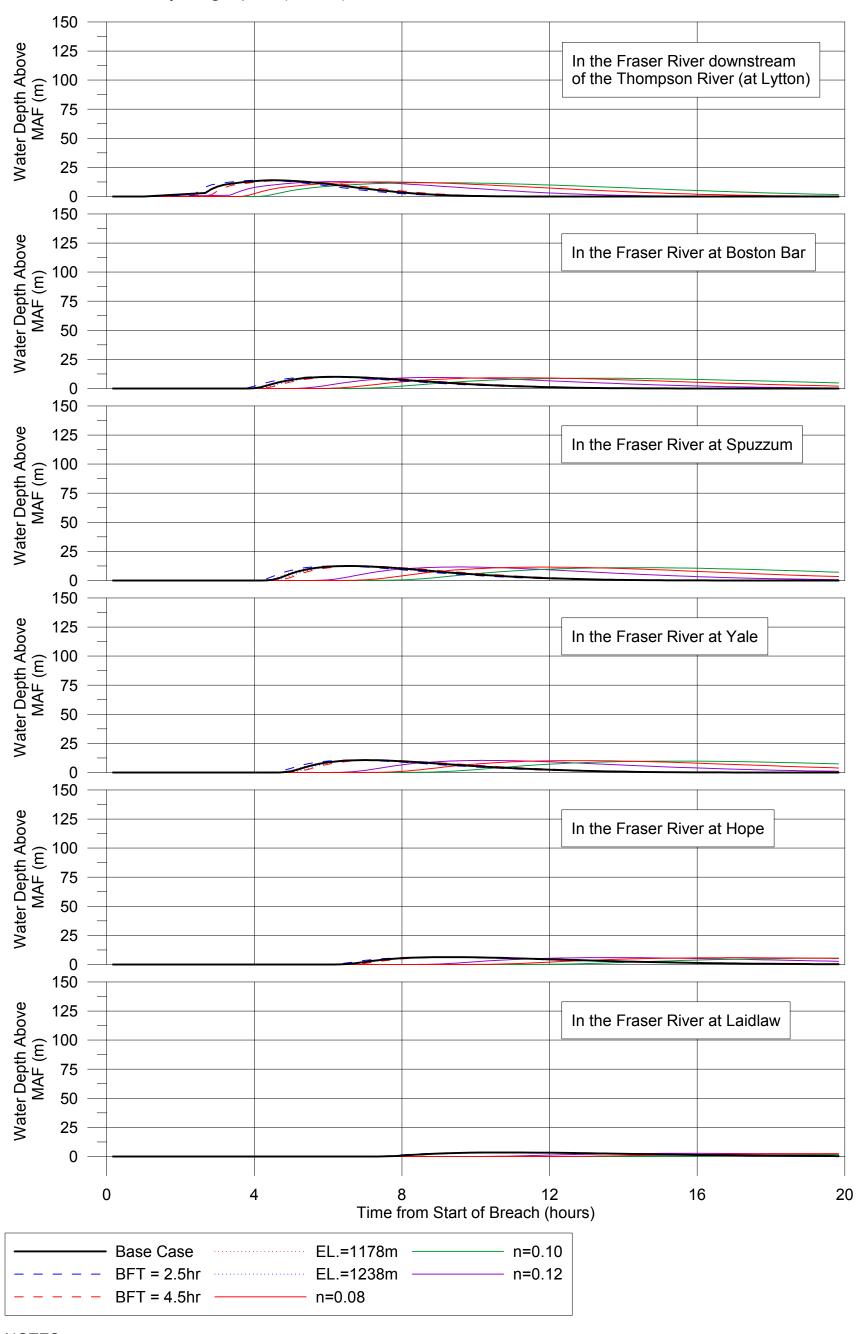
<sup>1.</sup> Base Case defined as Manning's n = 0.06 in the overbanks and 0.035 in the main channel. Breach Formation Time (BFT) = 3.5 hours. Initial piping elevation (EL.) = 1208 m.

Figure 5.2 Piping Breach, Water and Tailings Released - Sensitivity Analyses - Stage Hydrographs (1 of 2)



- 1. Base Case defined as Manning's n = 0.06 in the overbanks and 0.035 in the main channel. Breach Formation Time (BFT) = 3.5 hours. Initial piping elevation (EL.) = 1208 m.
- 2. Includes concurrent flow in rivers downstream of dam = Mean Annual Flow.

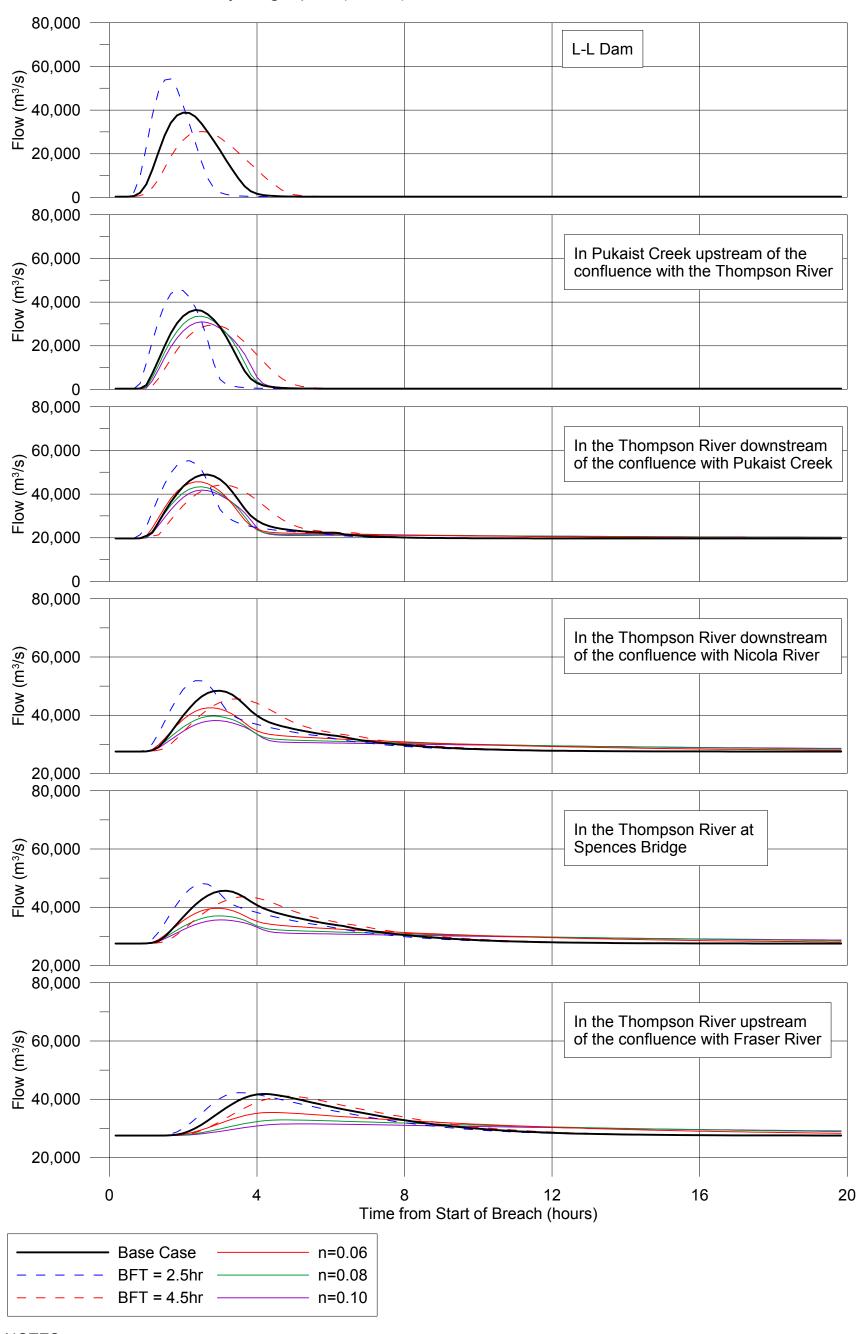
Figure 5.2 Piping Breach, Water and Tailings Released - Sensitivity Analyses - Stage Hydrographs (2 of 2)



2. Includes concurrent flow in rivers downstream of dam = Mean Annual Flow.

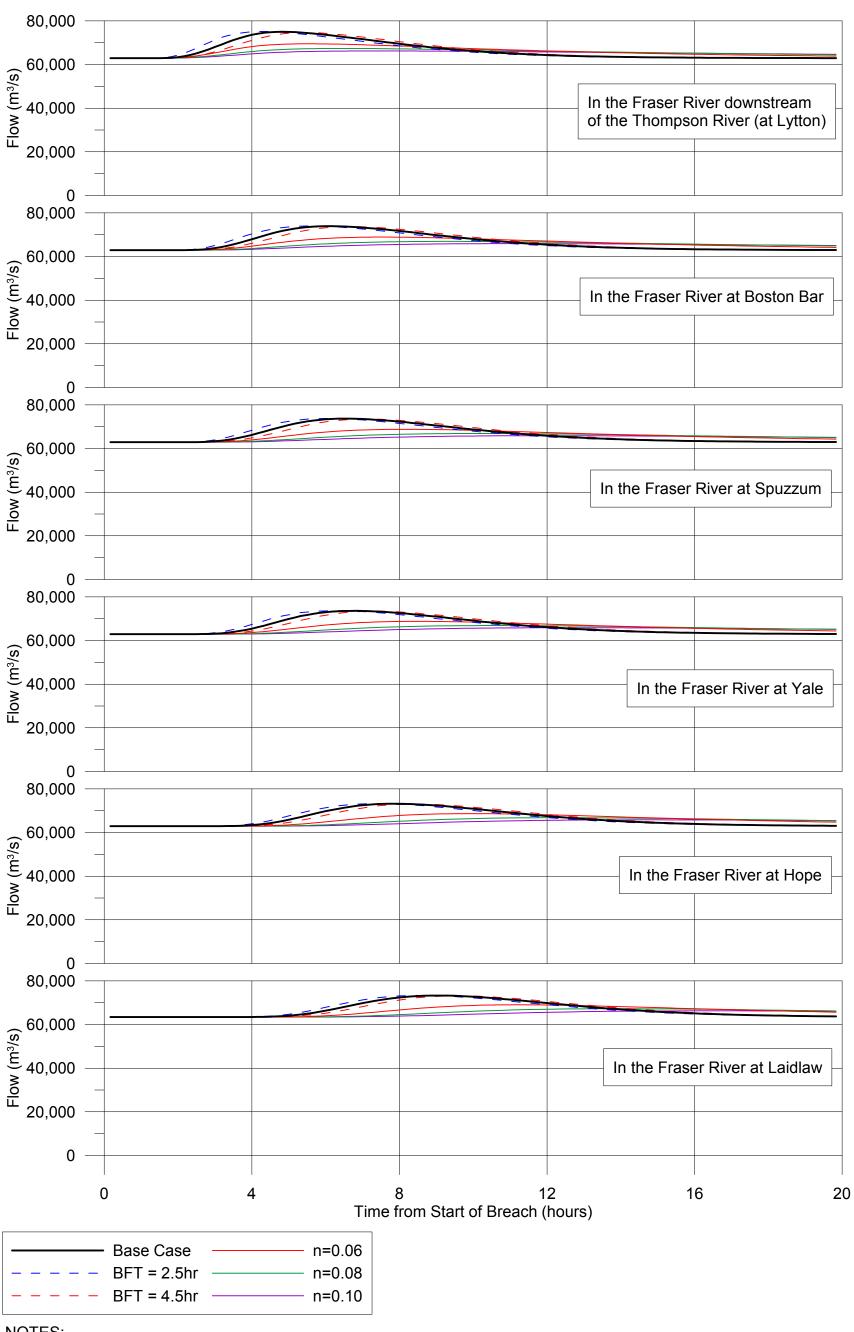
<sup>1.</sup> Base Case defined as Manning's n = 0.06 in the overbanks and 0.035 in the main channel. Breach Formation Time (BFT) = 3.5 hours. Initial piping elevation (EL.) = 1208 m.

Figure 5.3 Overtopping Breach, Water and Tailings Released - Sensitivity Analyses - Flood Hydrographs (1 of 2)



- 1. Base Case defined as Manning's n = 0.06 in the overbanks and 0.035 in the main channel. Breach Formation Time (BFT) = 3.5 hours.
- 2. Includes concurrent flow in rivers downstream of dam = Probable Maximum Flow.

Figure 5.3 Overtopping Breach, Water and Tailings Released - Sensitivity Analyses - Flood Hydrographs (2 of 2)



- 1. Base Case defined as Manning's n = 0.06 in the overbanks and 0.035 in the main channel. Breach Formation Time (BFT) = 3.5 hours.
- 2. Includes concurrent flow in rivers downstream of dam = Probable Maximum Flow.

Stage Hydrographs (1 of 2) 150 Water Depth Above 125 L-L Dam 100 PMF (m) 75 50 25 0 25 Water Depth Above 20 PMF (m) 15 10 In Pukaist Creek upstream of the confluence with the Thompson River 5 0 25 Water Depth Above 20 PMF (m) 15 10 In the Thompson River downstream of the confluence with Pukaist Creek 5 0 25 Water Depth Above PMF (m) 20 15 10 In the Thompson River downstream of the confluence with Nicola River 5 0 25 Water Depth Above 20 PMF (m) 15 10 In the Thompson River at Spences Bridge 5 0 25 Water Depth Above PMF (m) 2 01 10 02 In the Thompson River upstream of the confluence with Fraser River 0 0 12 16 20 Time from Start of Breach (hours)

Overtopping Breach, Water and Tailings Released - Sensitivity Analyses -Figure 5.4

Base Case BFT = 2.5hr

BFT = 4.5hr

n=0.06

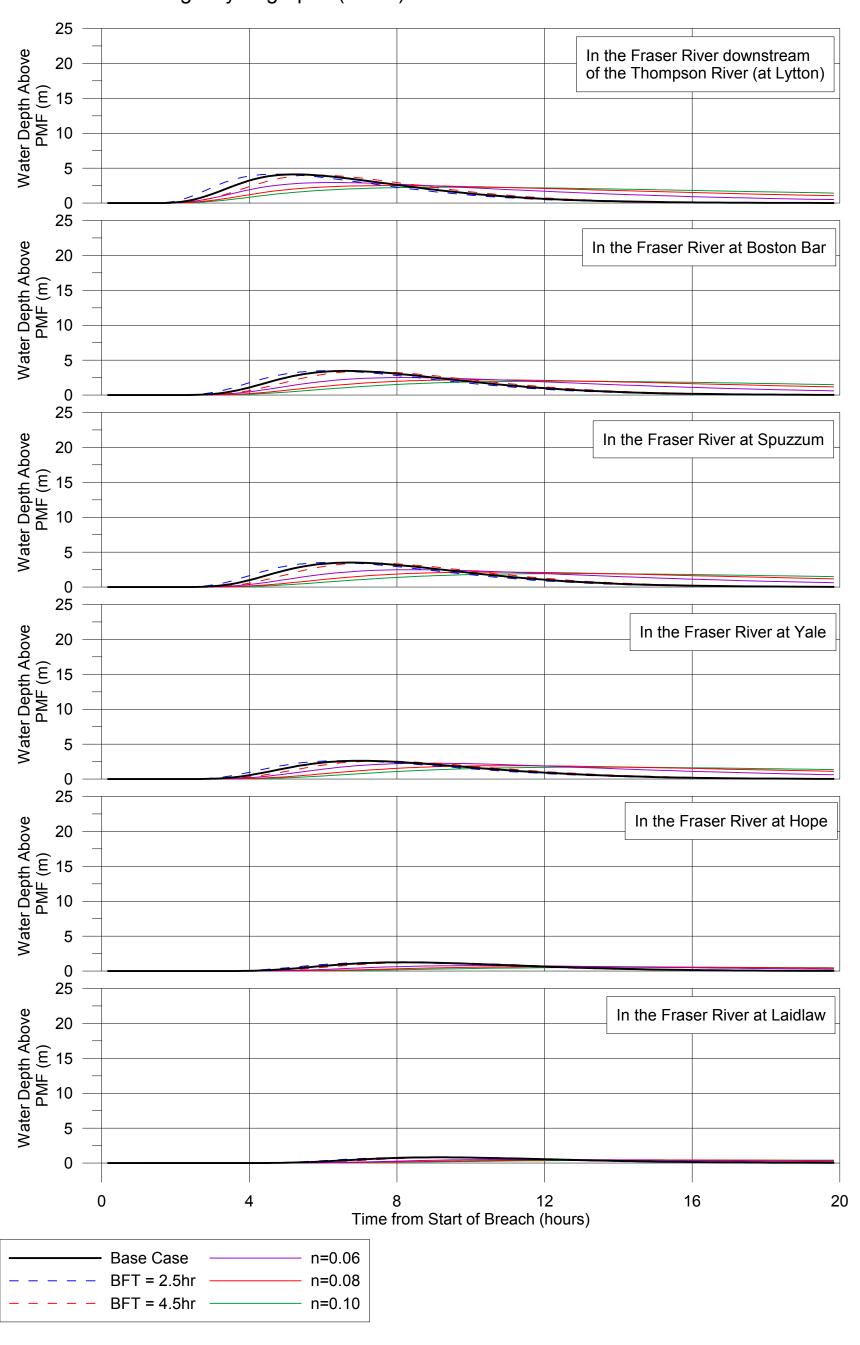
n=0.08

n=0.10

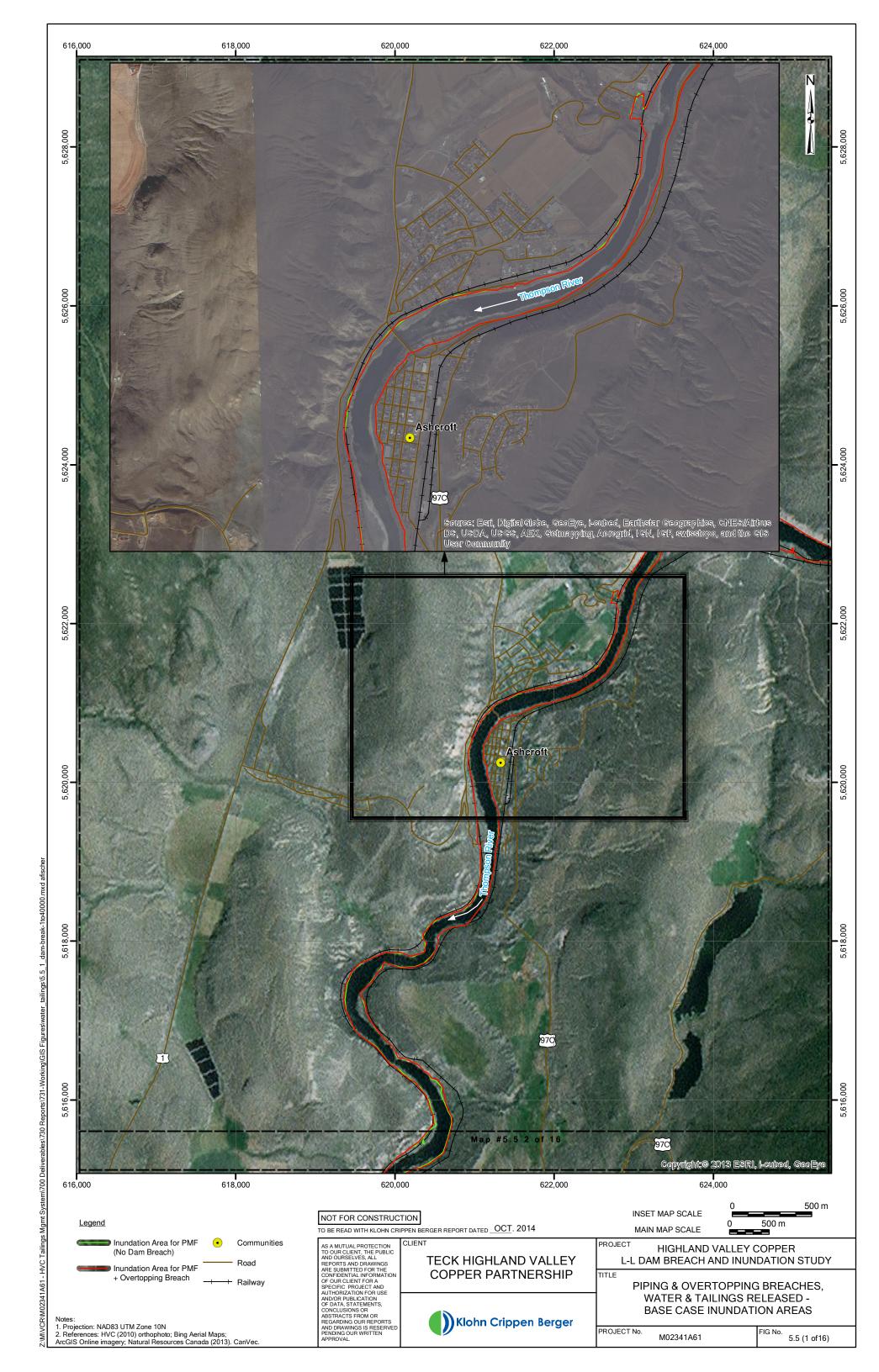
<sup>1.</sup> Base Case defined as Manning's n = 0.06 in the overbanks and 0.035 in the main channel. Breach Formation Time (BFT) = 3.5 hours.

<sup>2.</sup> Includes concurrent flow in rivers downstream of dam = Probable Maximum Flow.

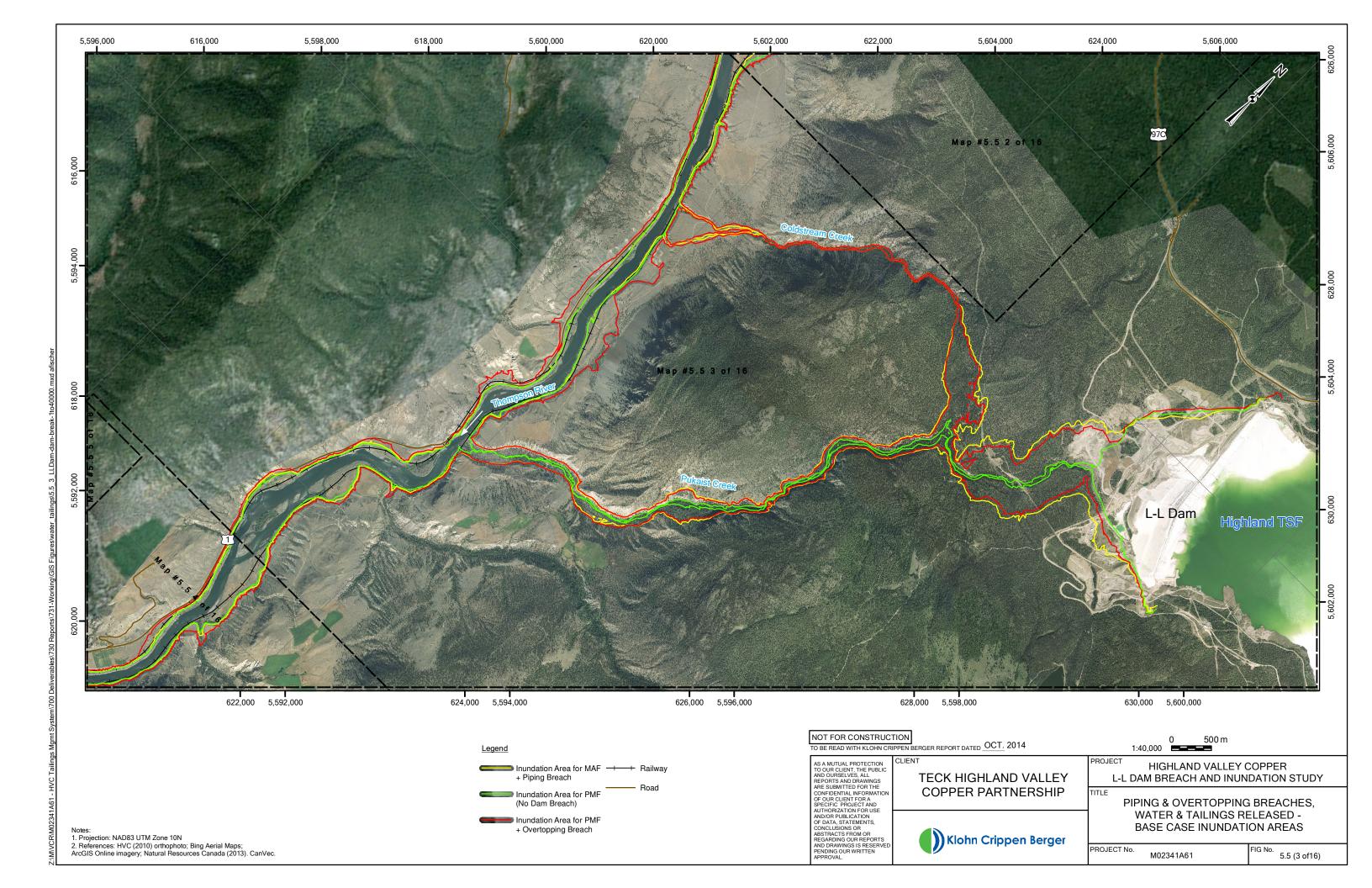
Figure 5.4 Overtopping Breach, Water and Tailings Released - Sensitivity Analyses - Stage Hydrographs (2 of 2)

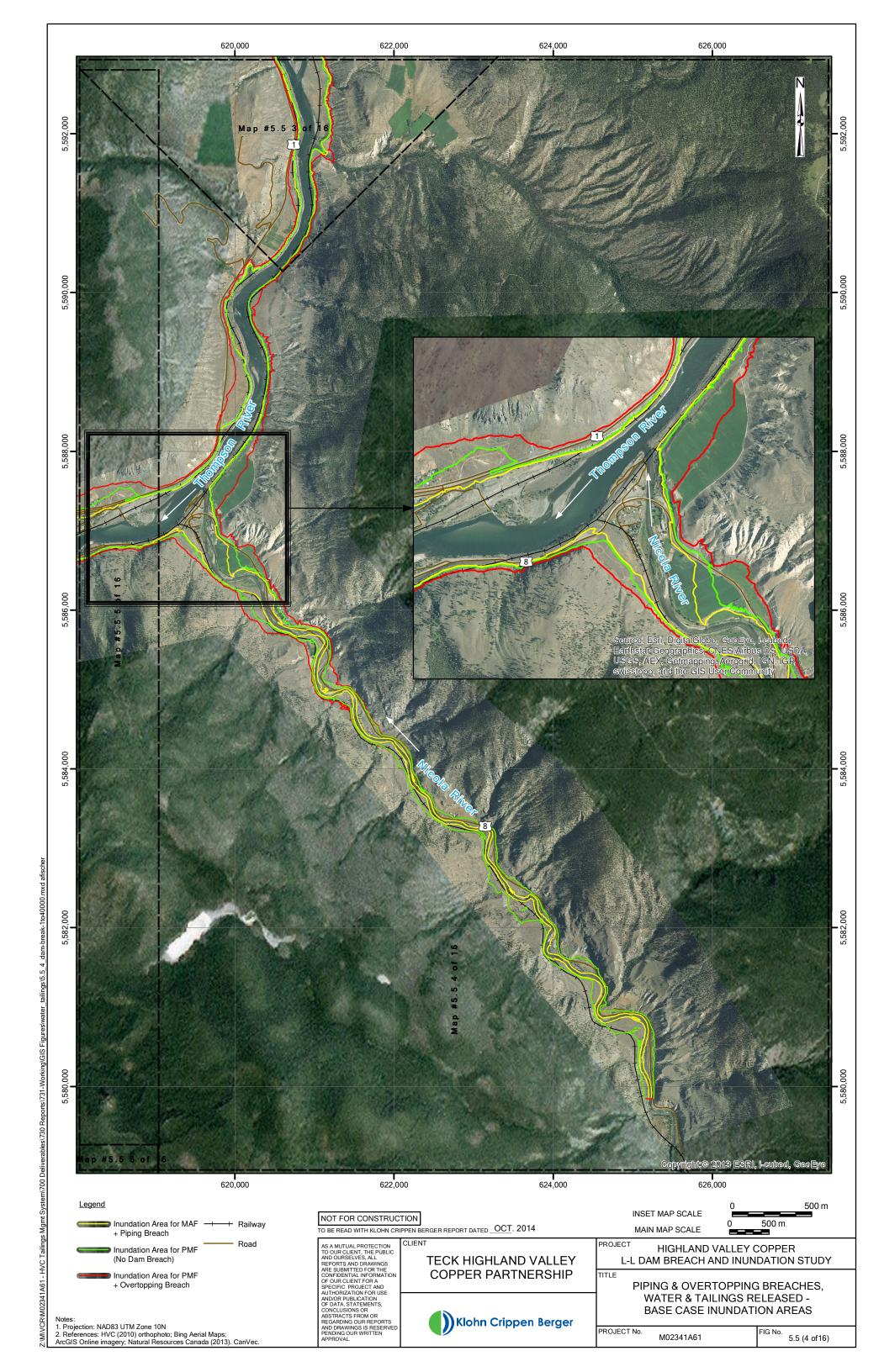


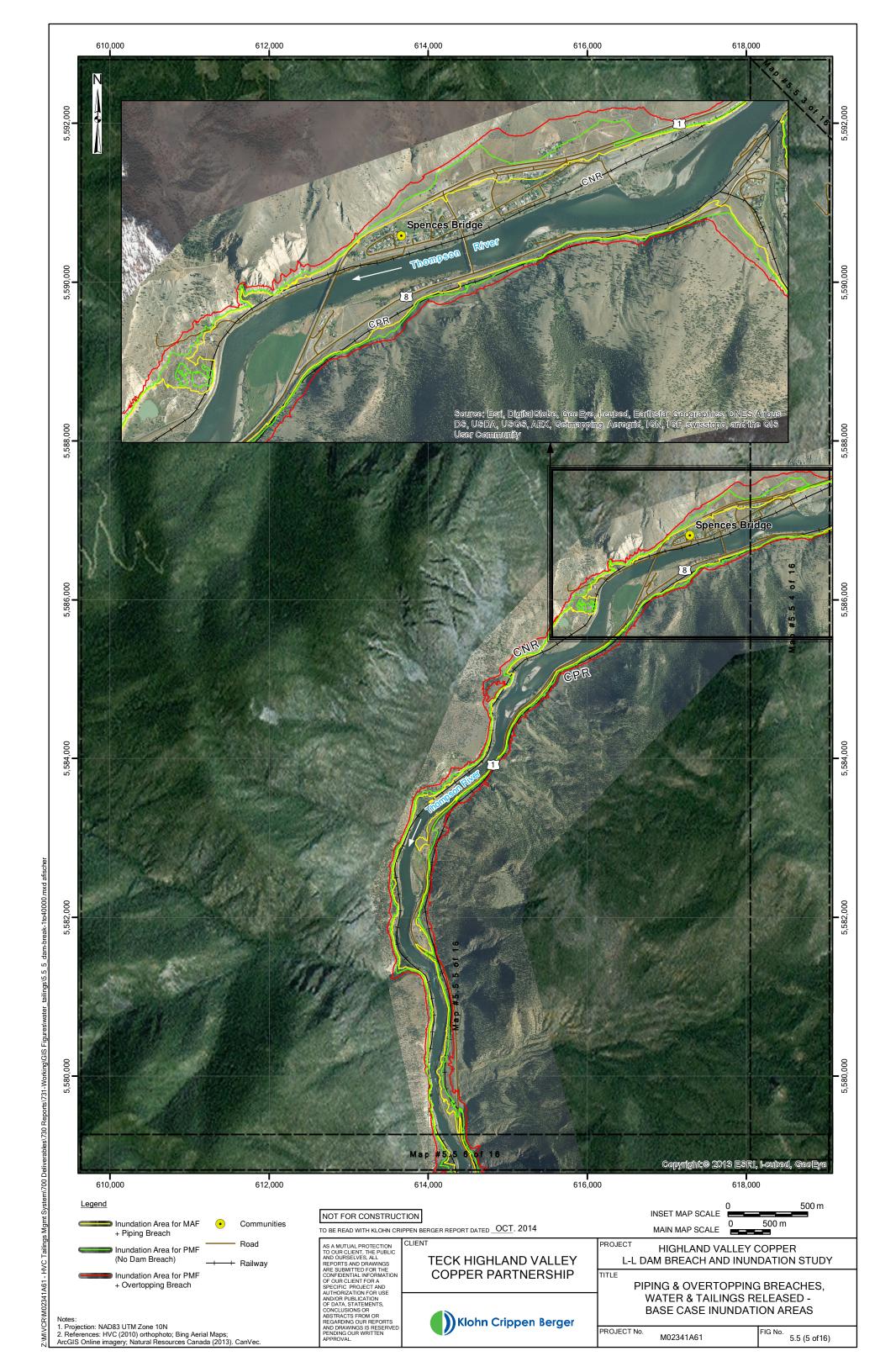
- 1. Base Case defined as Manning's n = 0.06 in the overbanks and 0.035 in the main channel. Breach Formation Time (BFT) = 3.5 hours.
- 2. Includes concurrent flow in rivers downstream of dam = Probable Maximum Flow.

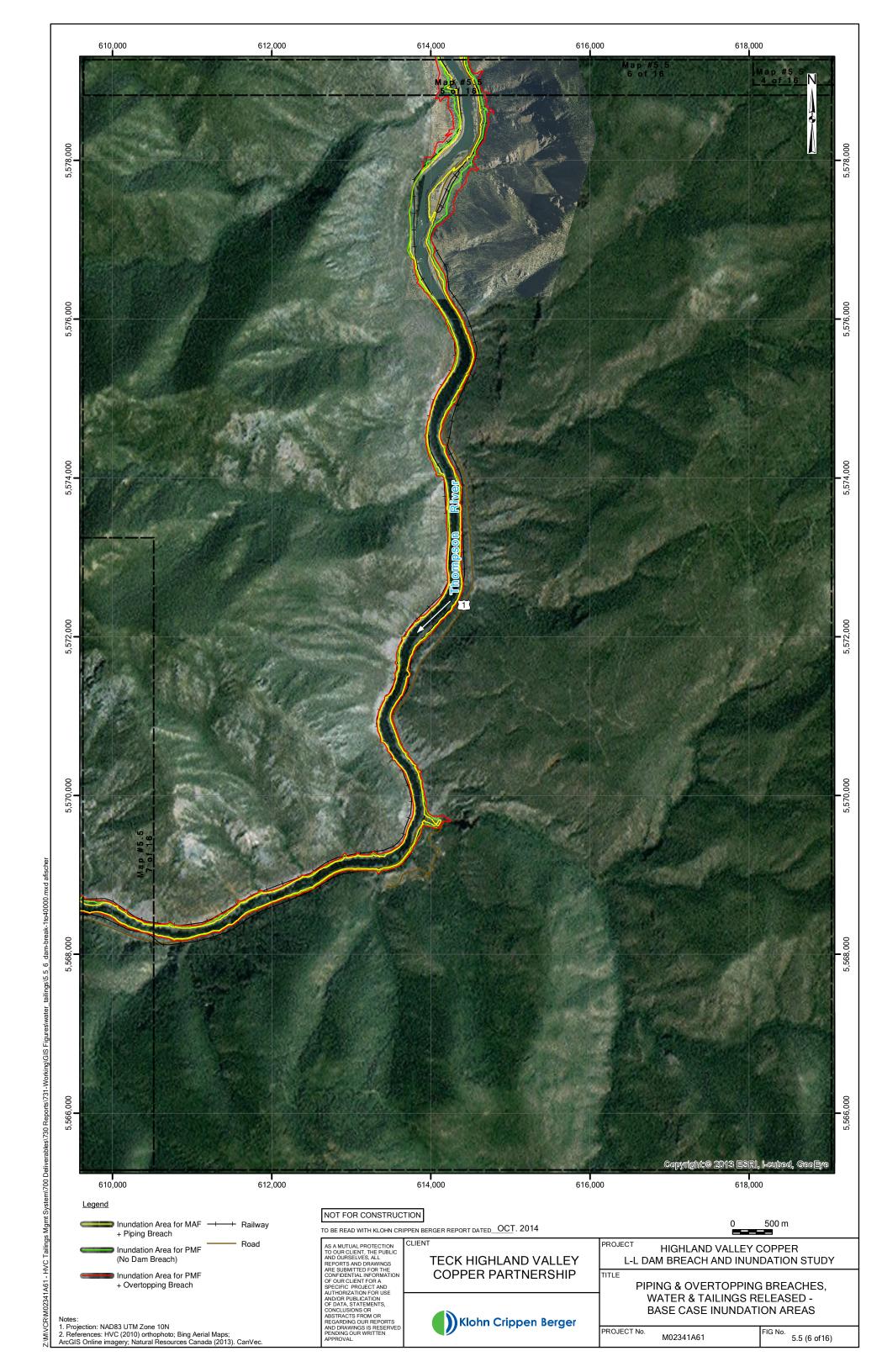


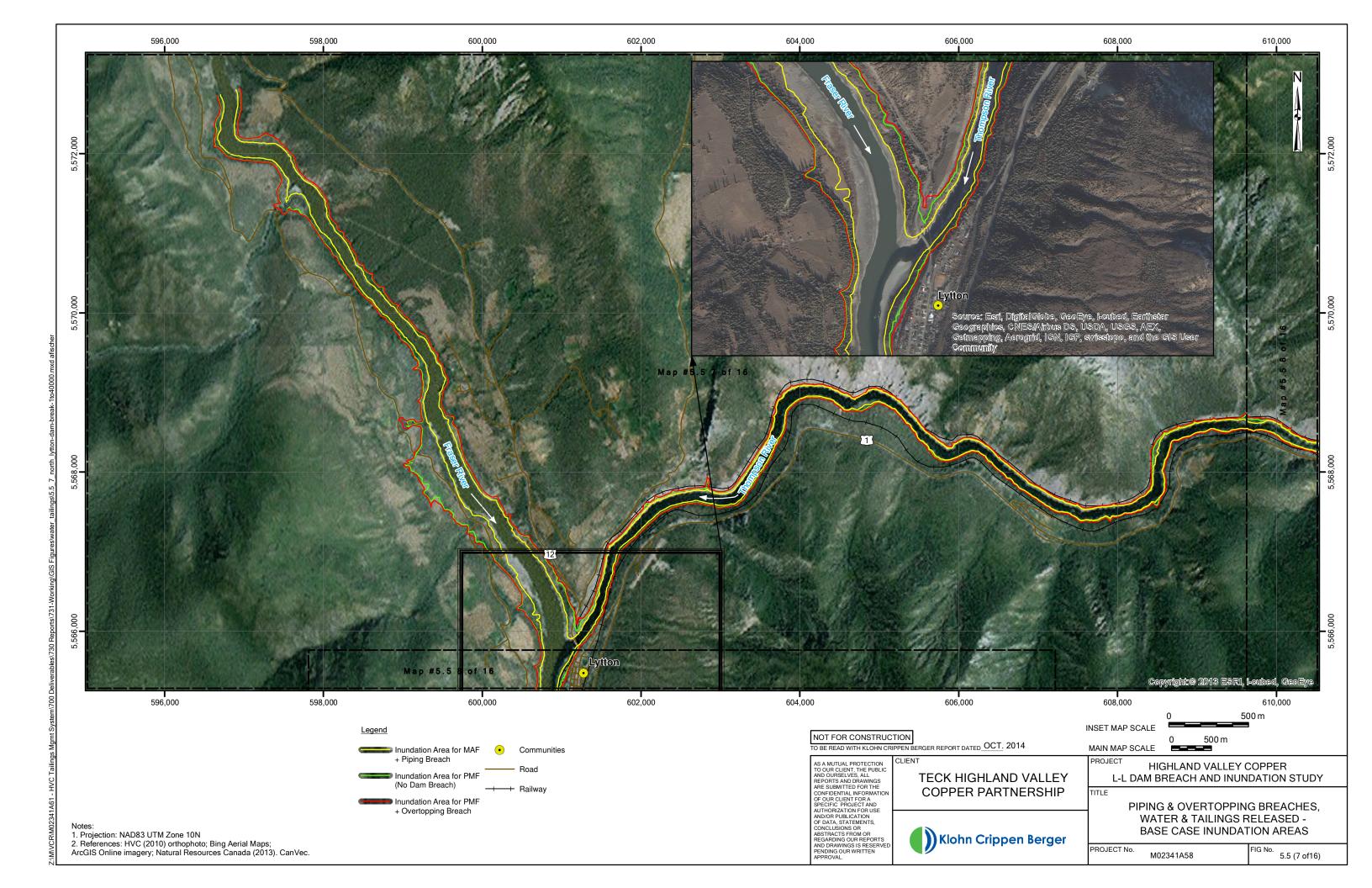


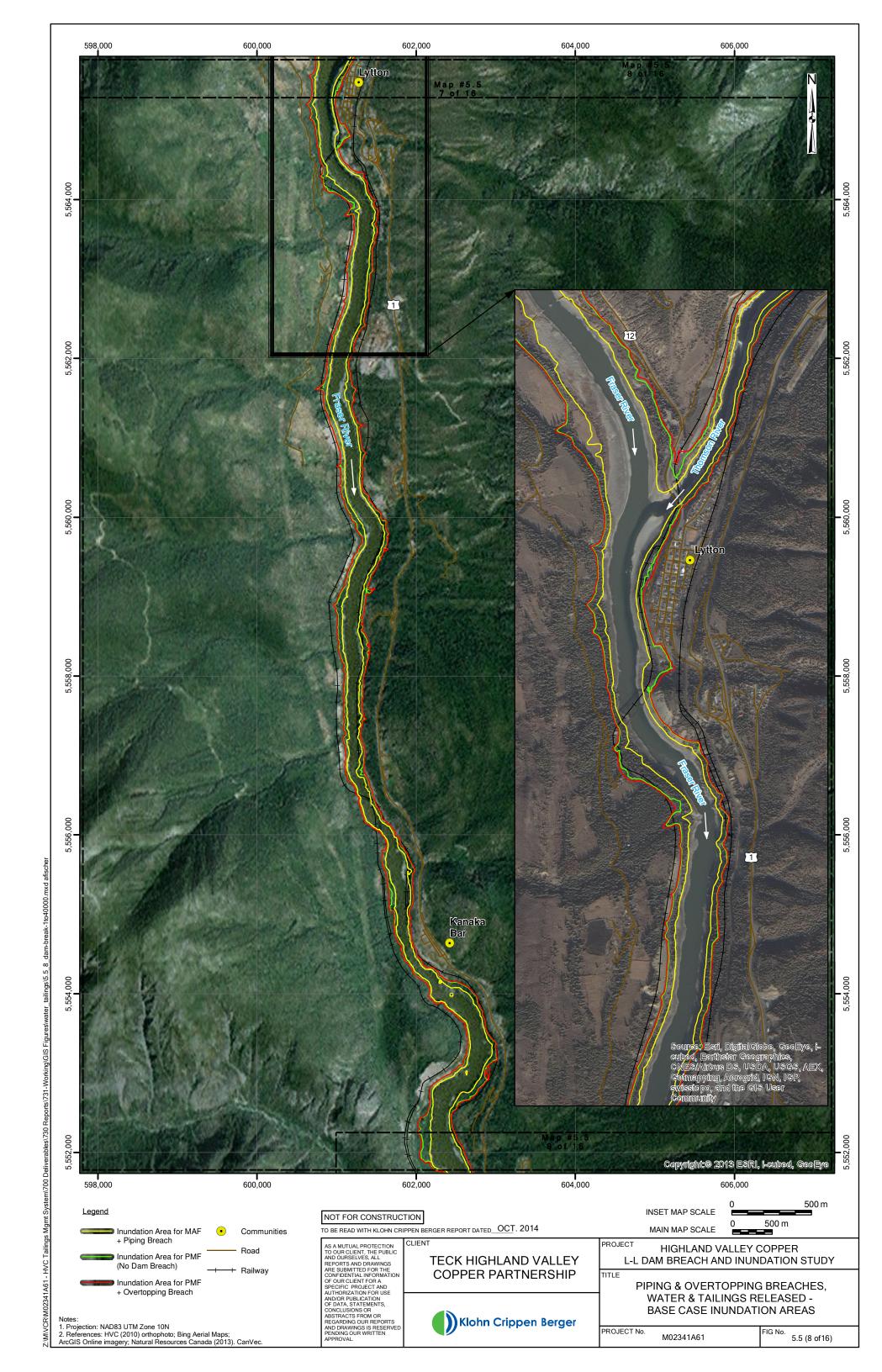


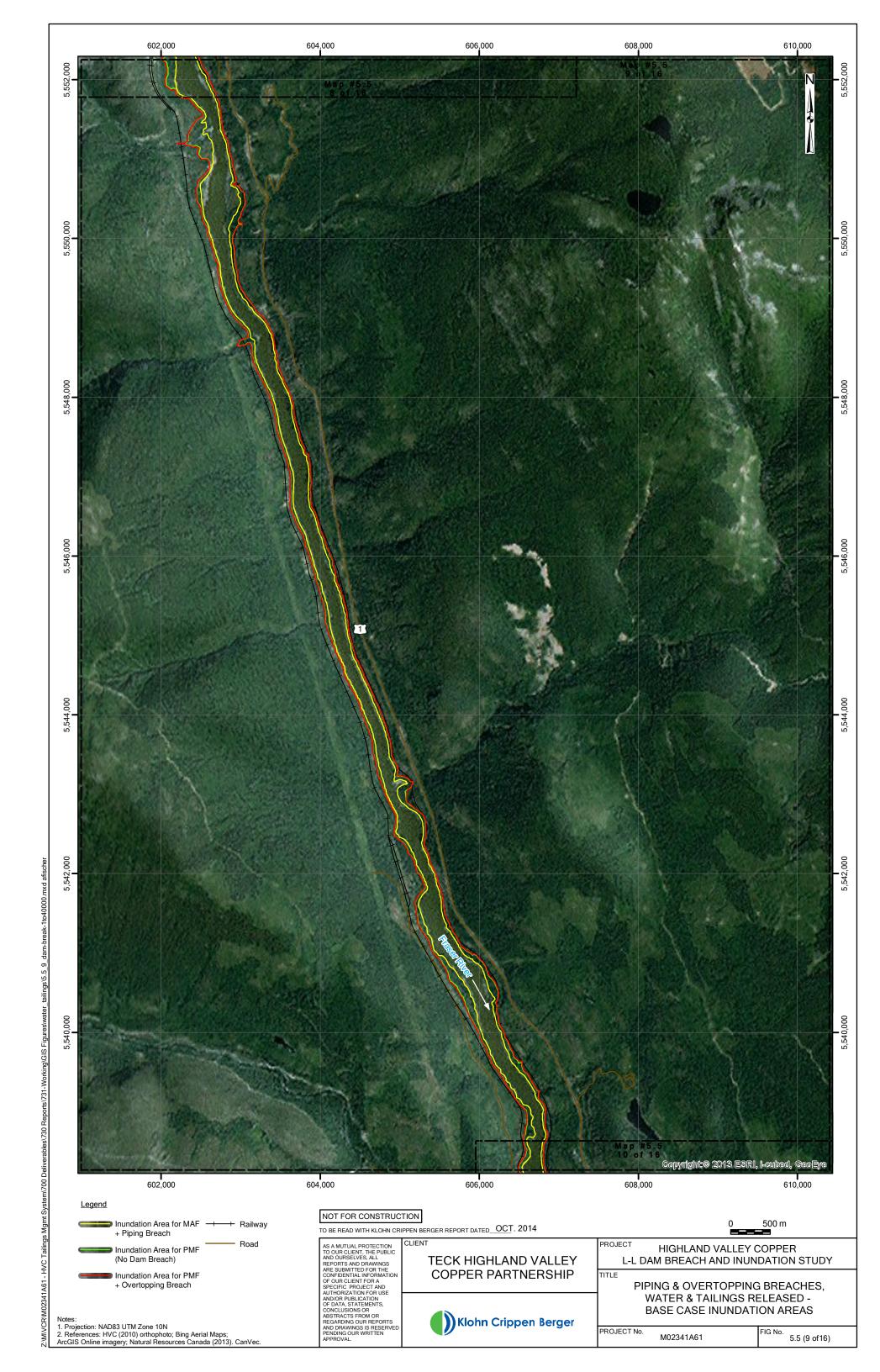


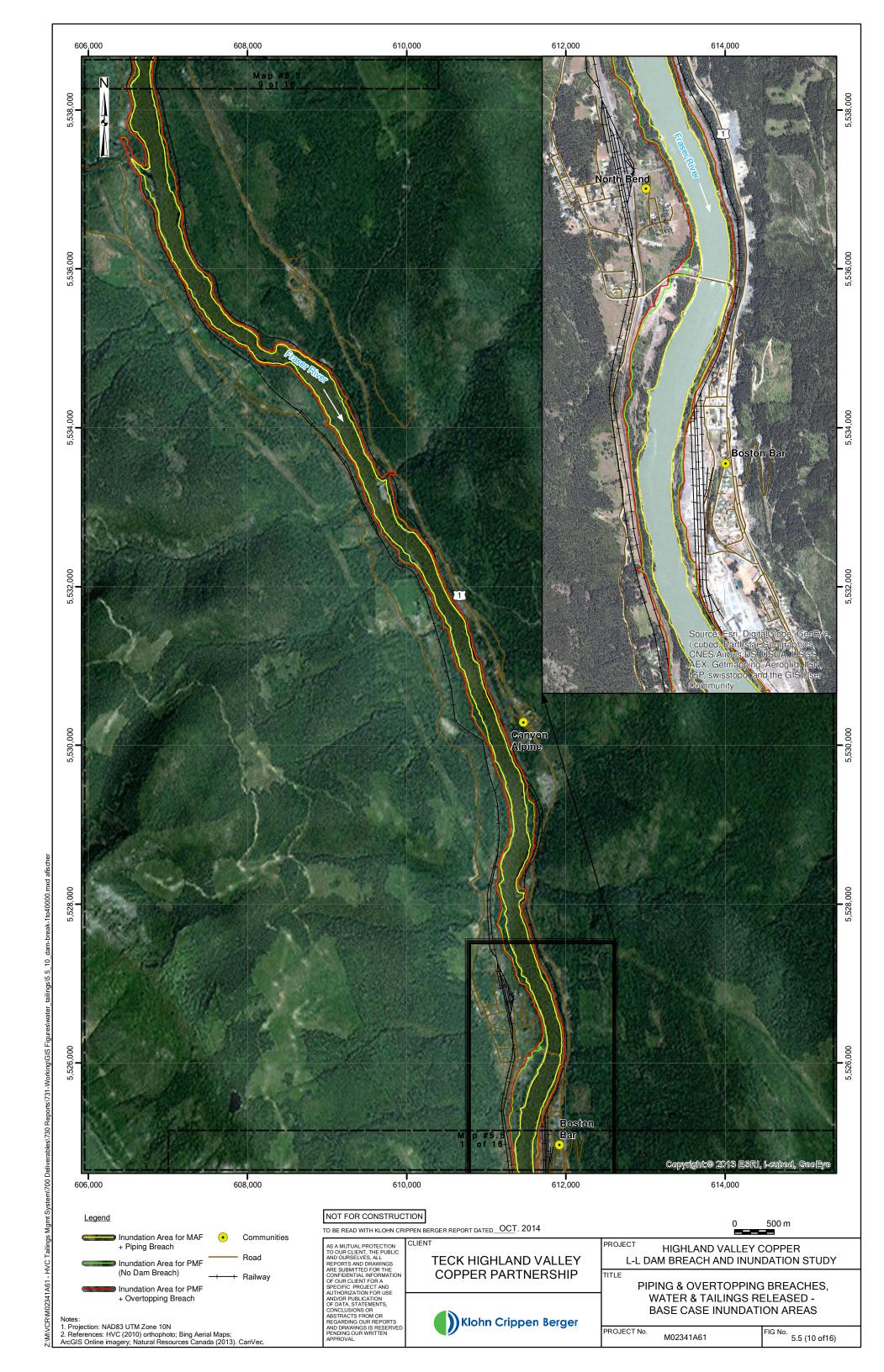


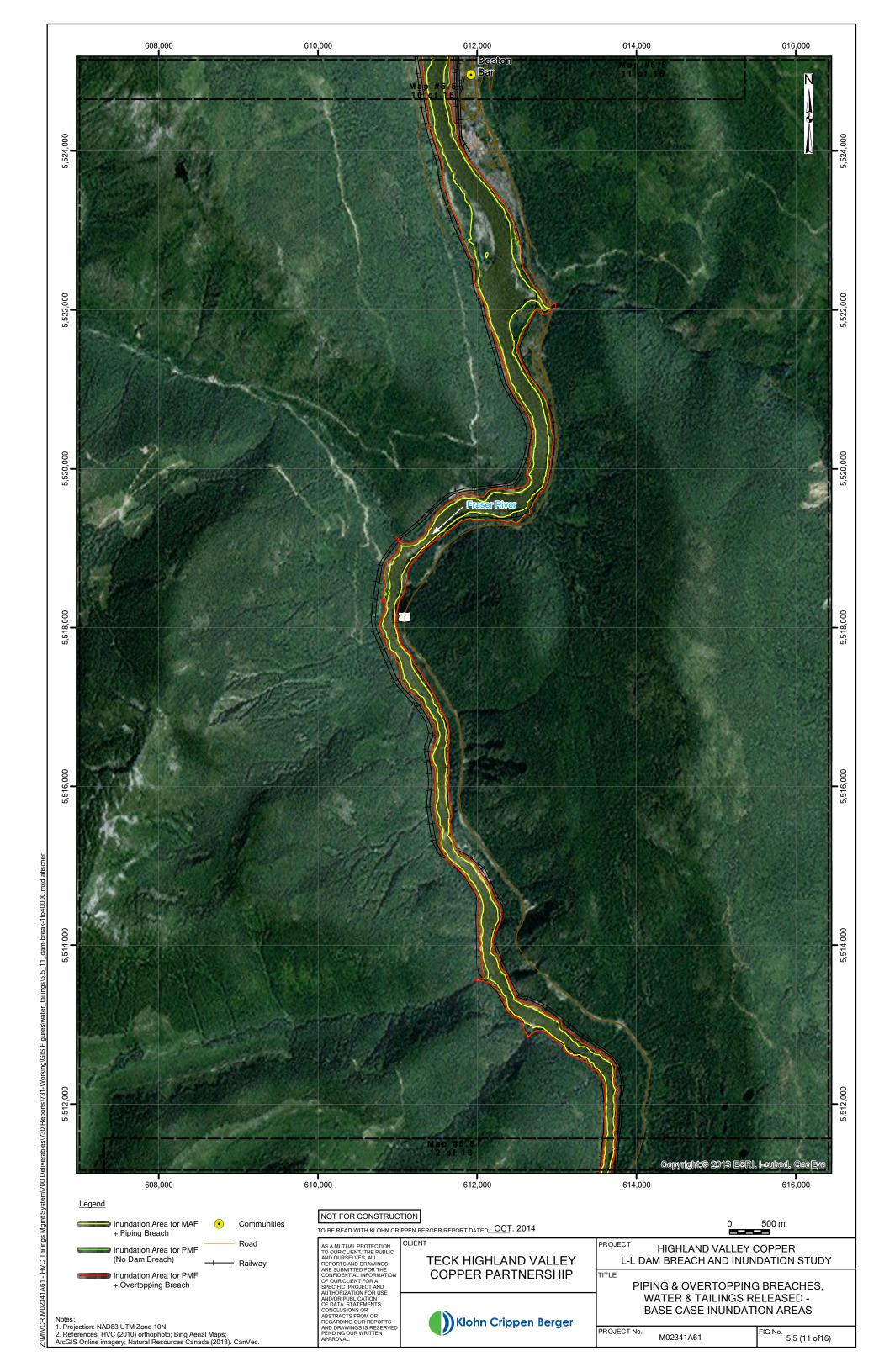


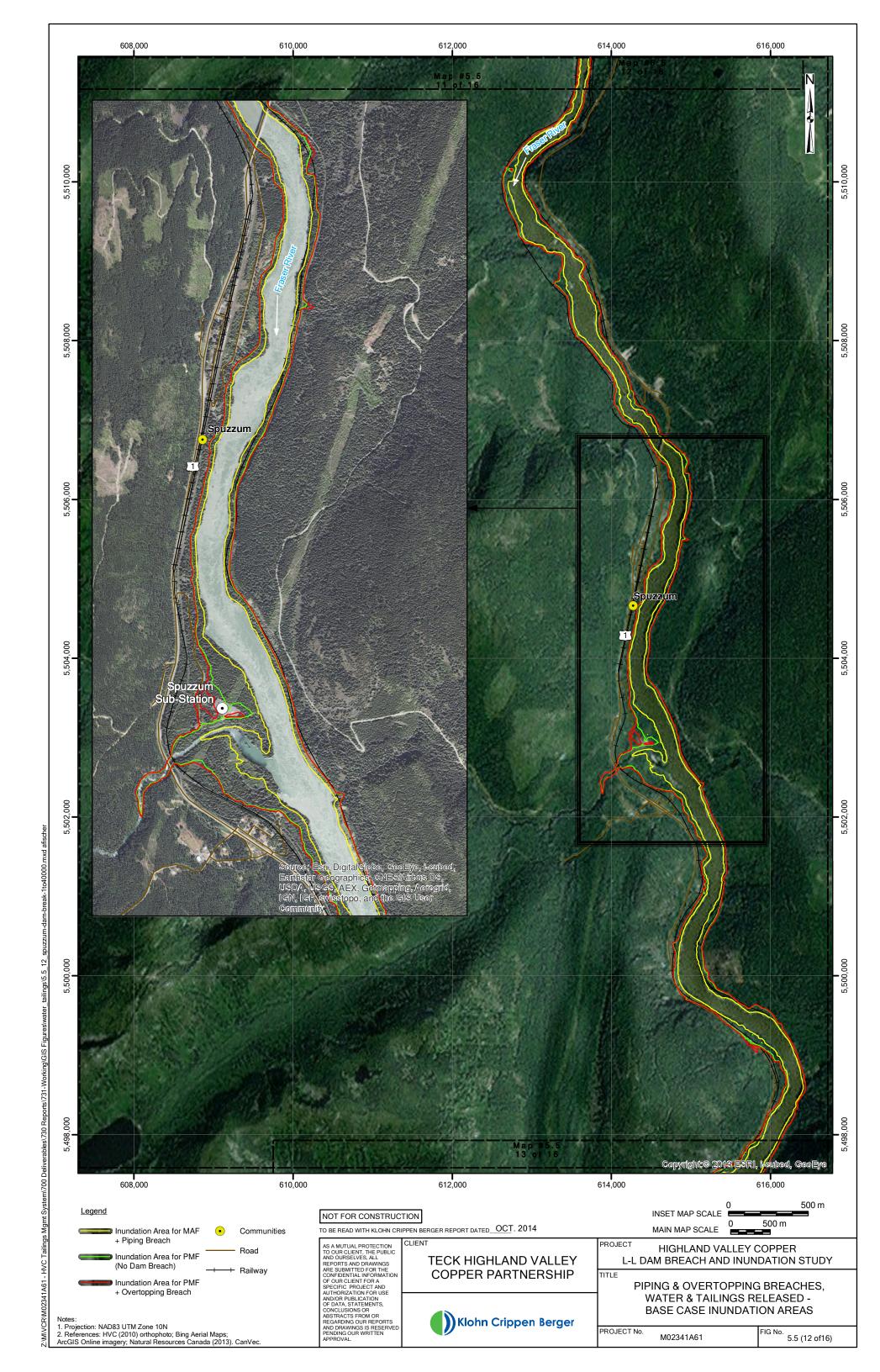


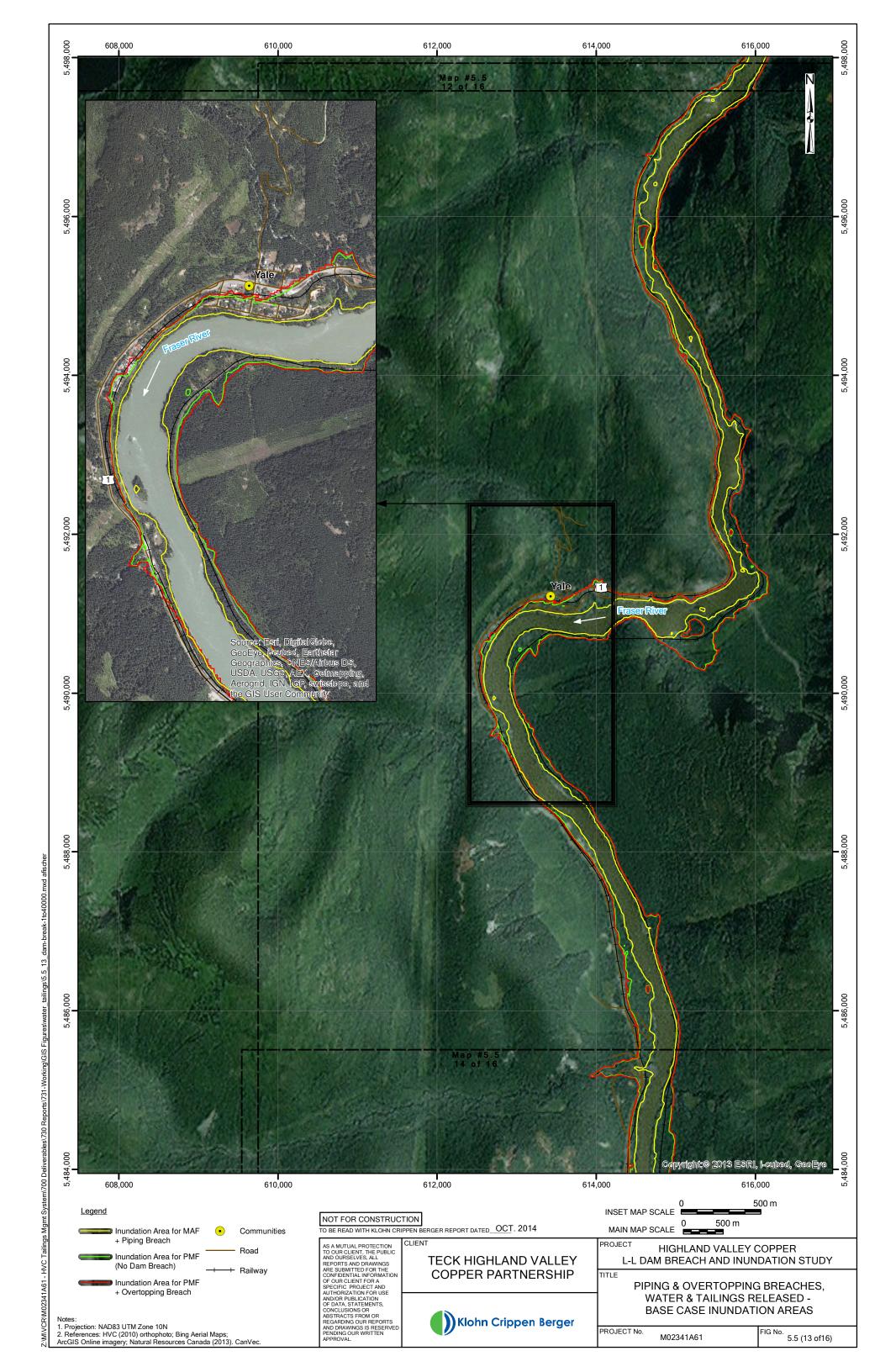




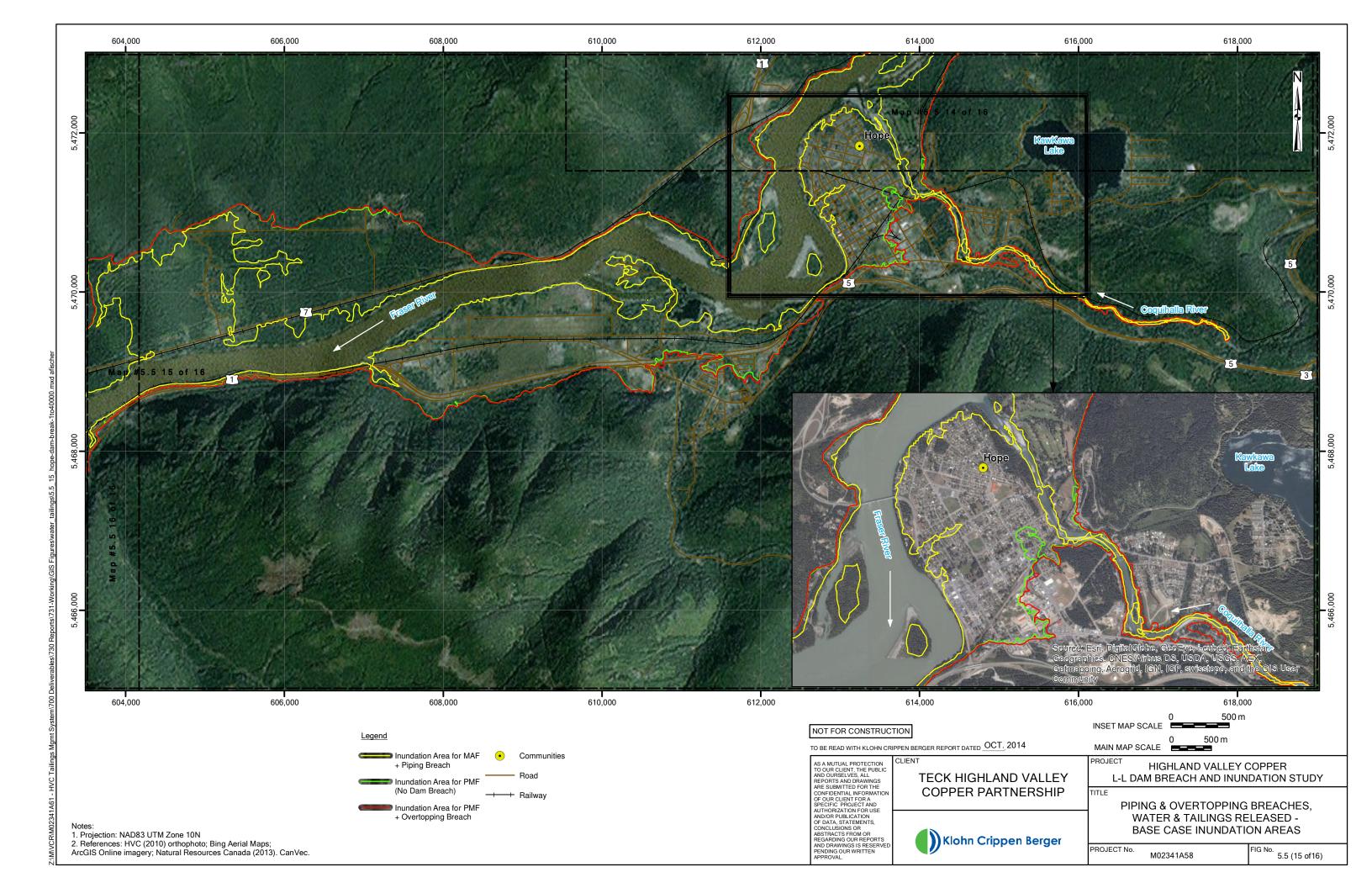


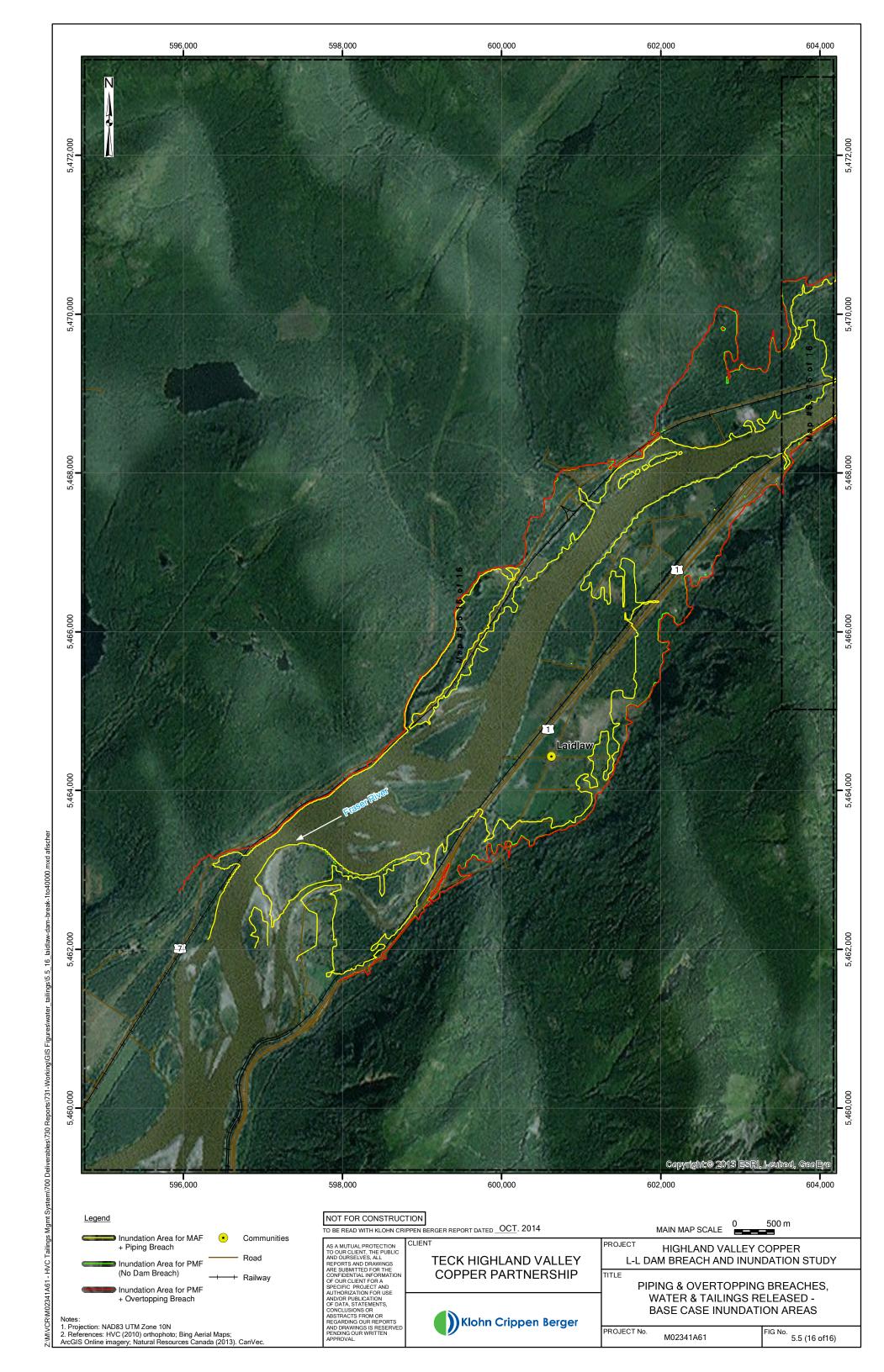












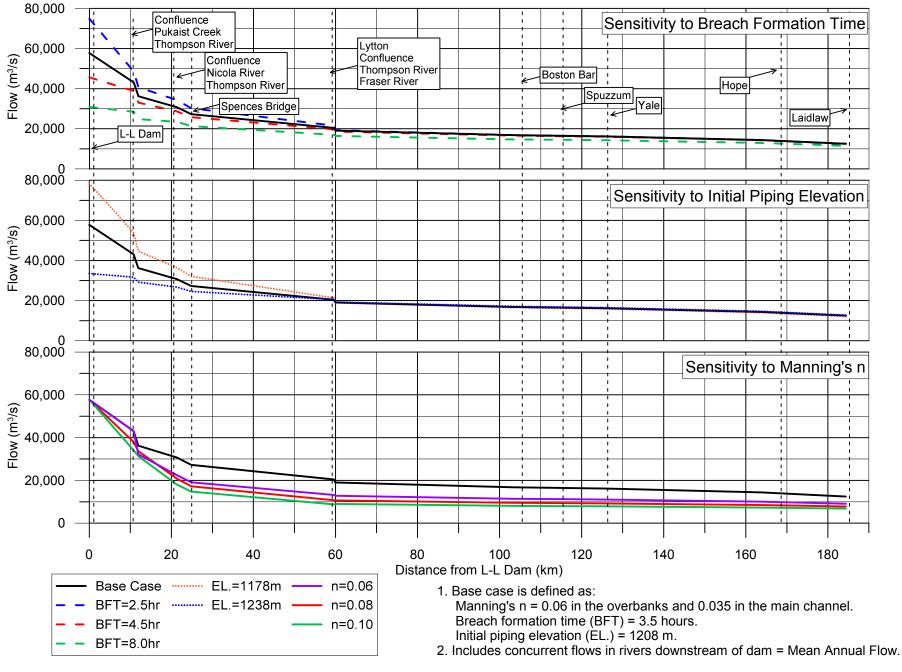


Figure 5.6 Piping Breach, Water and Tailings Released - Peak Flows d/s of L-L Dam

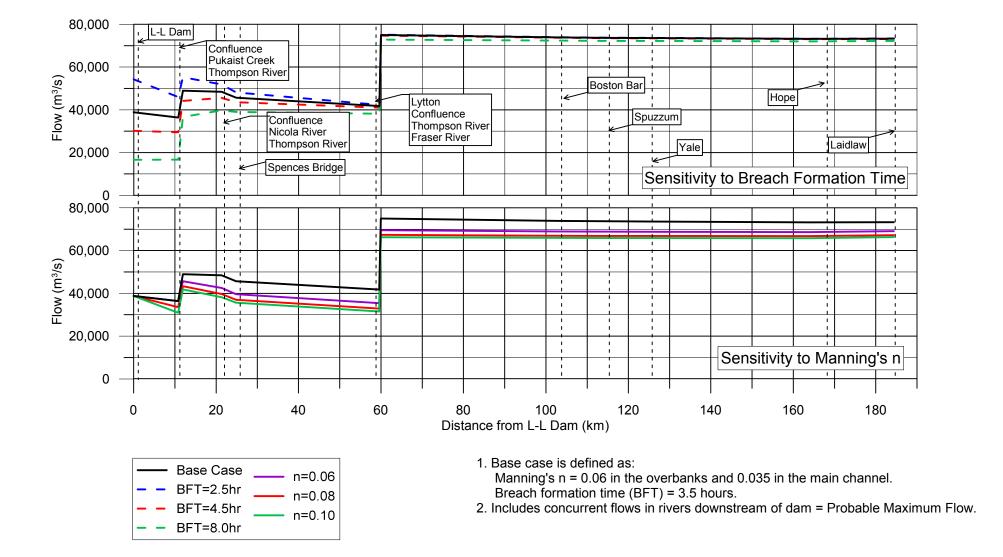


Figure 5.7 Overtopping Breach, Water and Tailings Released - Peak Flows d/s of L-L Dam

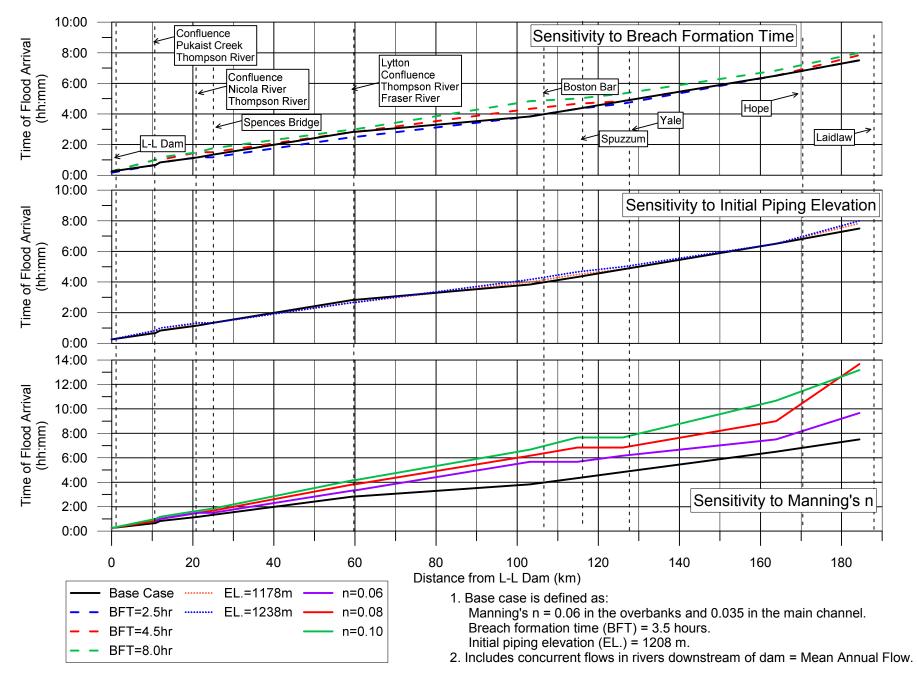


Figure 5.8 Piping Breach, Water and Tailings Released - Flood Arrival Time d/s of L-L Dam

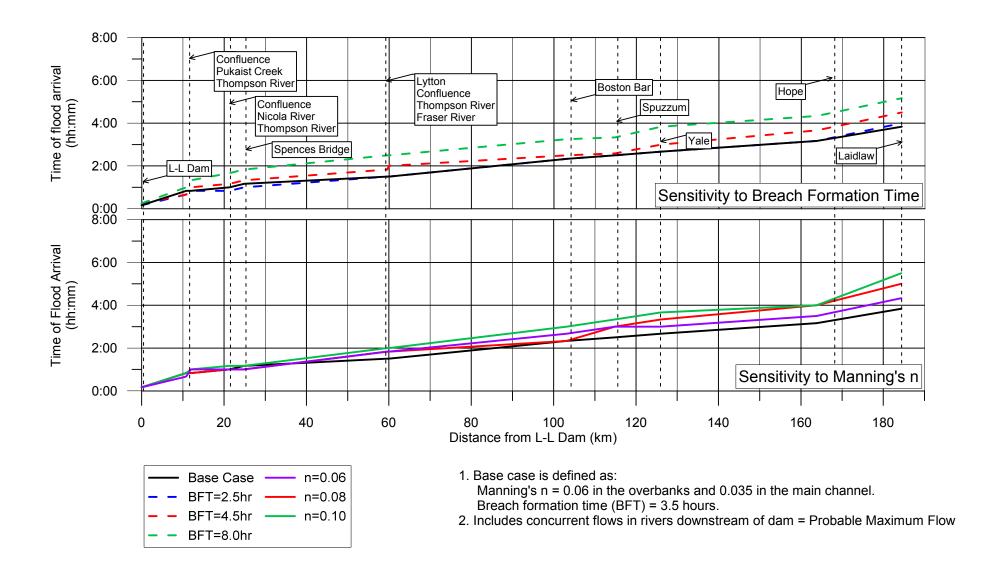


Figure 5.9 Overtopping Breach, Water and Tailings Released - Flood Arrival Time d/s of L-L Dam

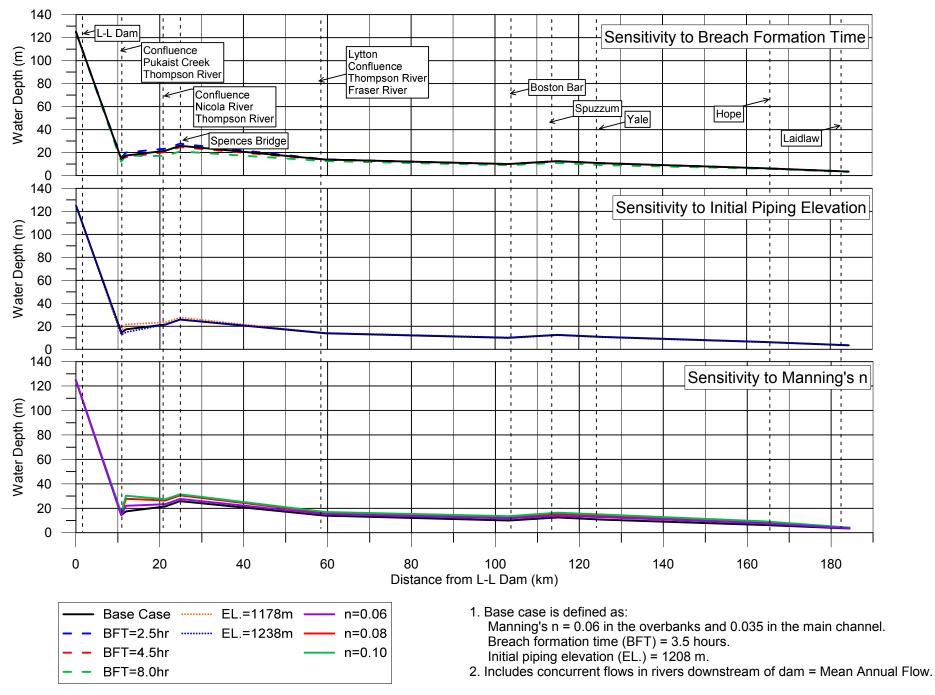


Figure 5.10 Piping Breach, Water and Tailings Released - Peak Water Depths above MAF d/s of L-L Dam

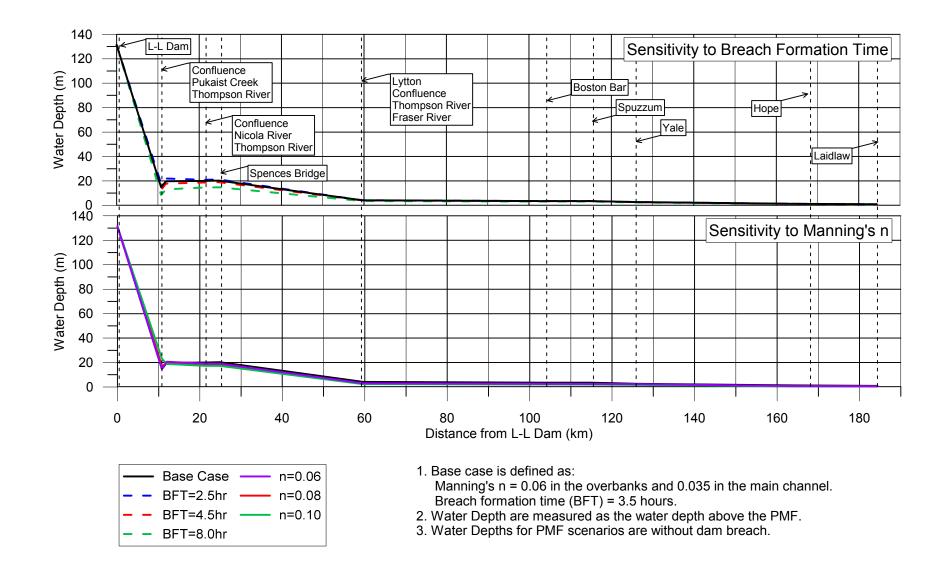


Figure 5.11 Overtopping Breach, Water and Tailings Released - Peak Water Depth above PMF d/s of L-L Dam

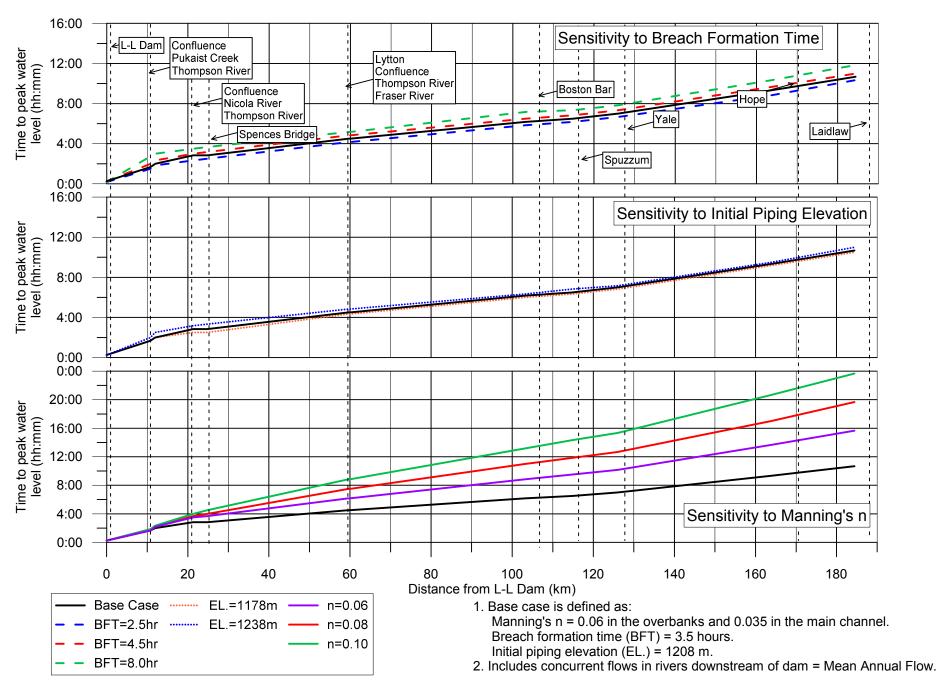


Figure 5.12 Piping Breach, Water and Tailings Released - Time to Peak Water Level d/s of L-L Dam

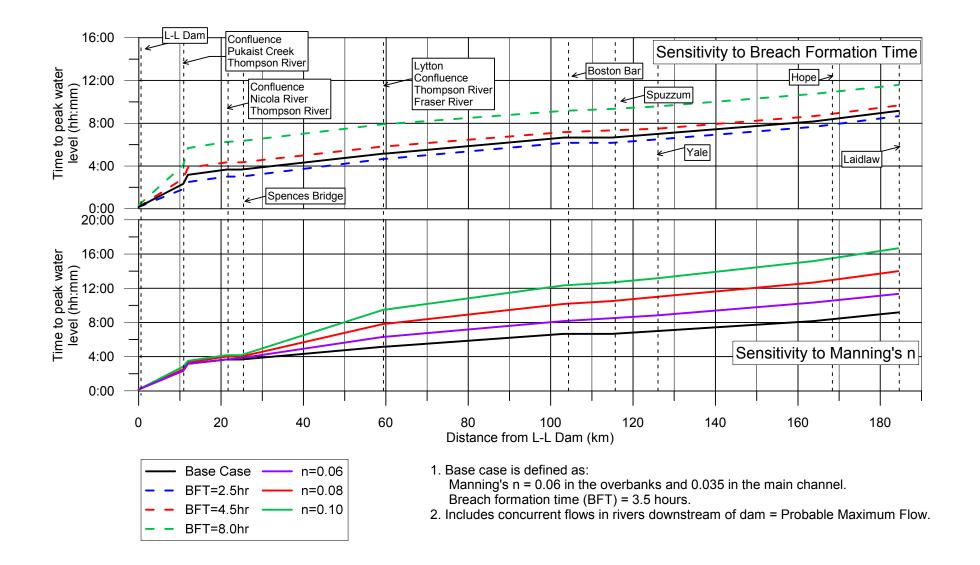
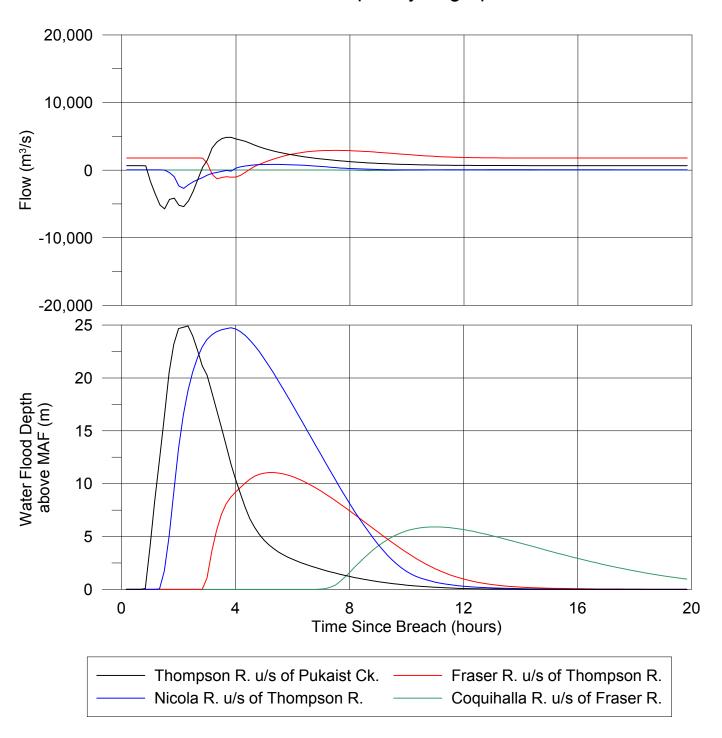


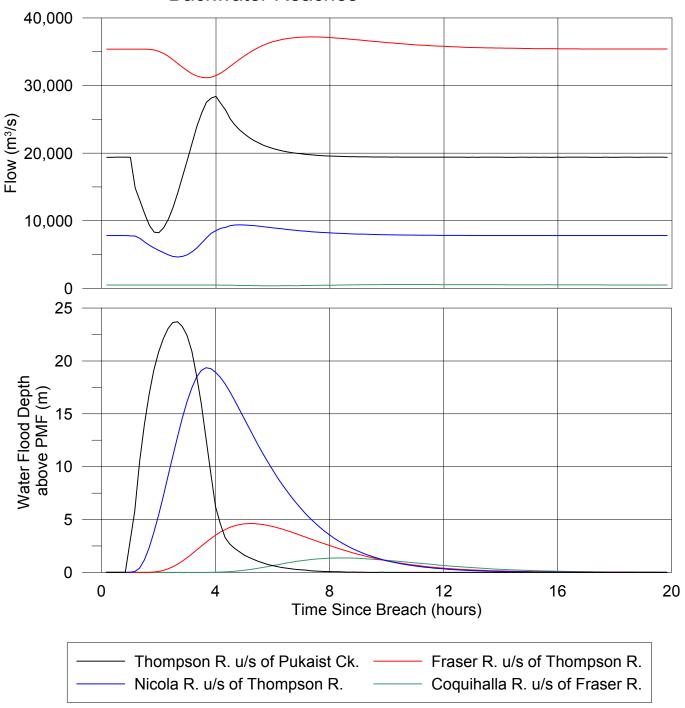
Figure 5.13 Overtopping Breach, Water and Tailings Released - Time to Peak Water Level d/s of L-L Dam

Figure 5.14 Piping Breach, Water and Tailings Released - Base Case Flow and Water Depth Hydrographs in Backwater Reaches



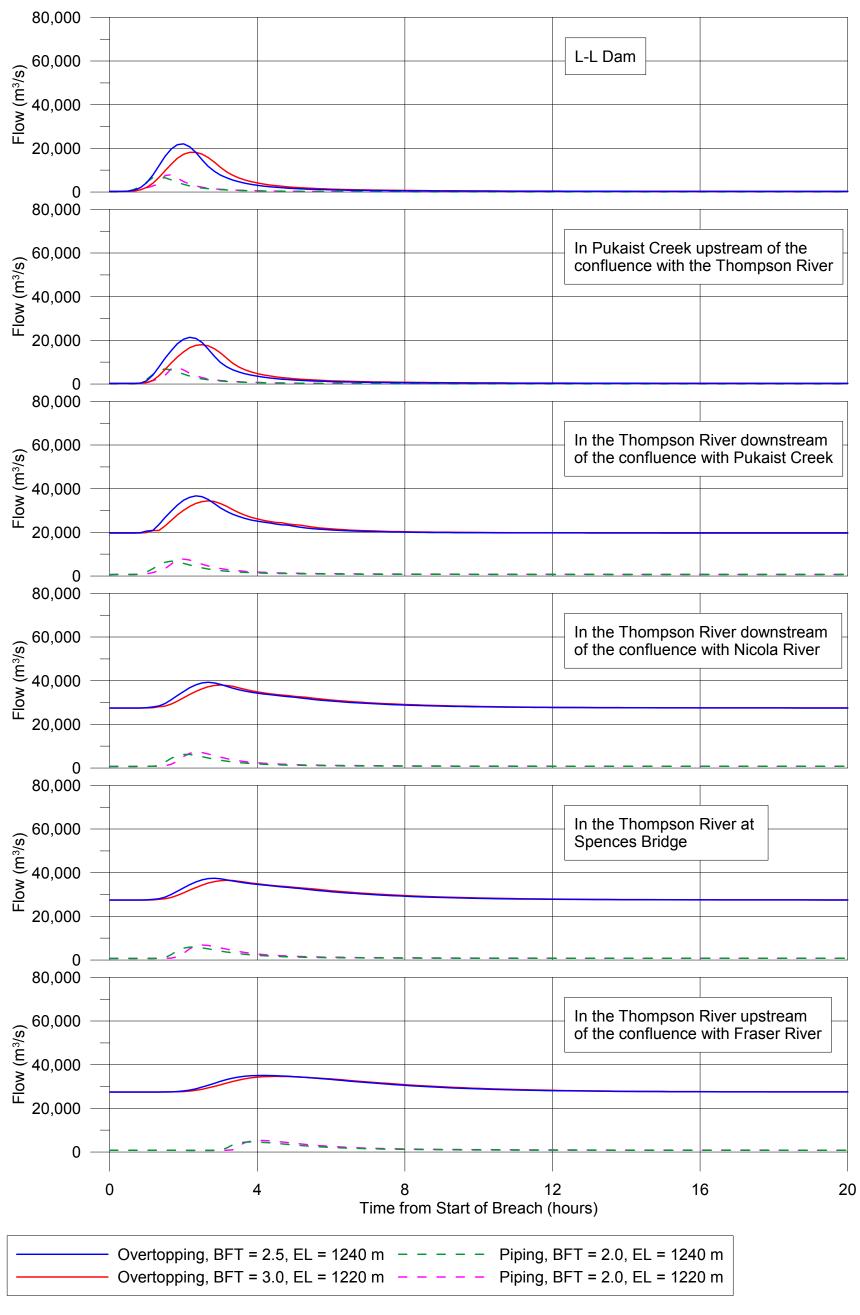
# NOTES: Includes concurrent flow in rivers downstream of dam = Mean Annual Flow (MAF).

Figure 5.15 Overtopping Breach, Water and Tailings Released - Base Case Flow and Water Depth Hydrographs in Backwater Reaches



# NOTES: Includes concurrent flow in rivers downstream of dam = Probable Maximum Flood (PMF).

Figure 5.16 Piping and Overtopping Breaches, Release of Water Only - Flood Hydrographs (1 of 2)

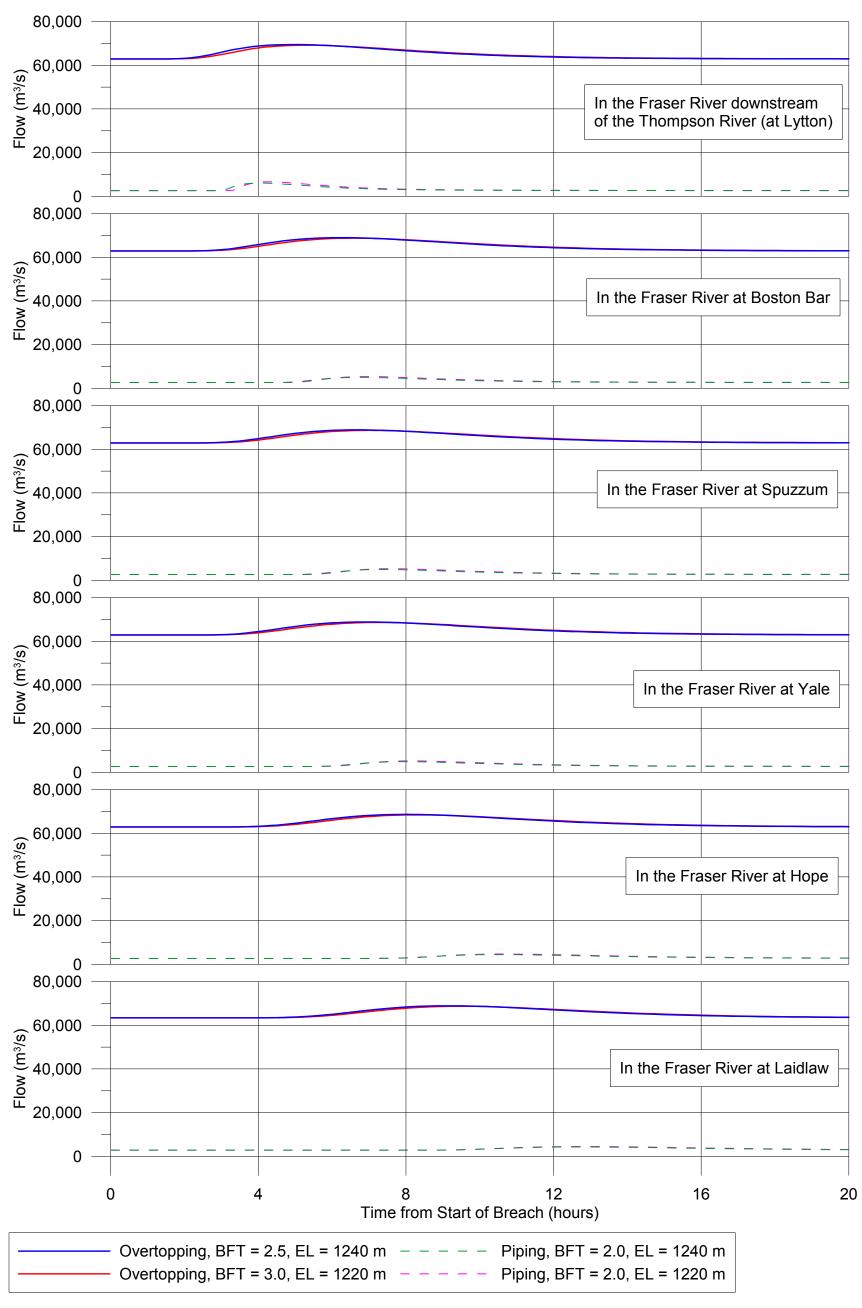


<sup>1.</sup> Concurrent flow in rivers downstream of dam is Probable Maximum Flow for Overtopping failure and Mean Annual Flow for Piping Failure.

<sup>2.</sup> BFT = Breach Formation Time in hour.

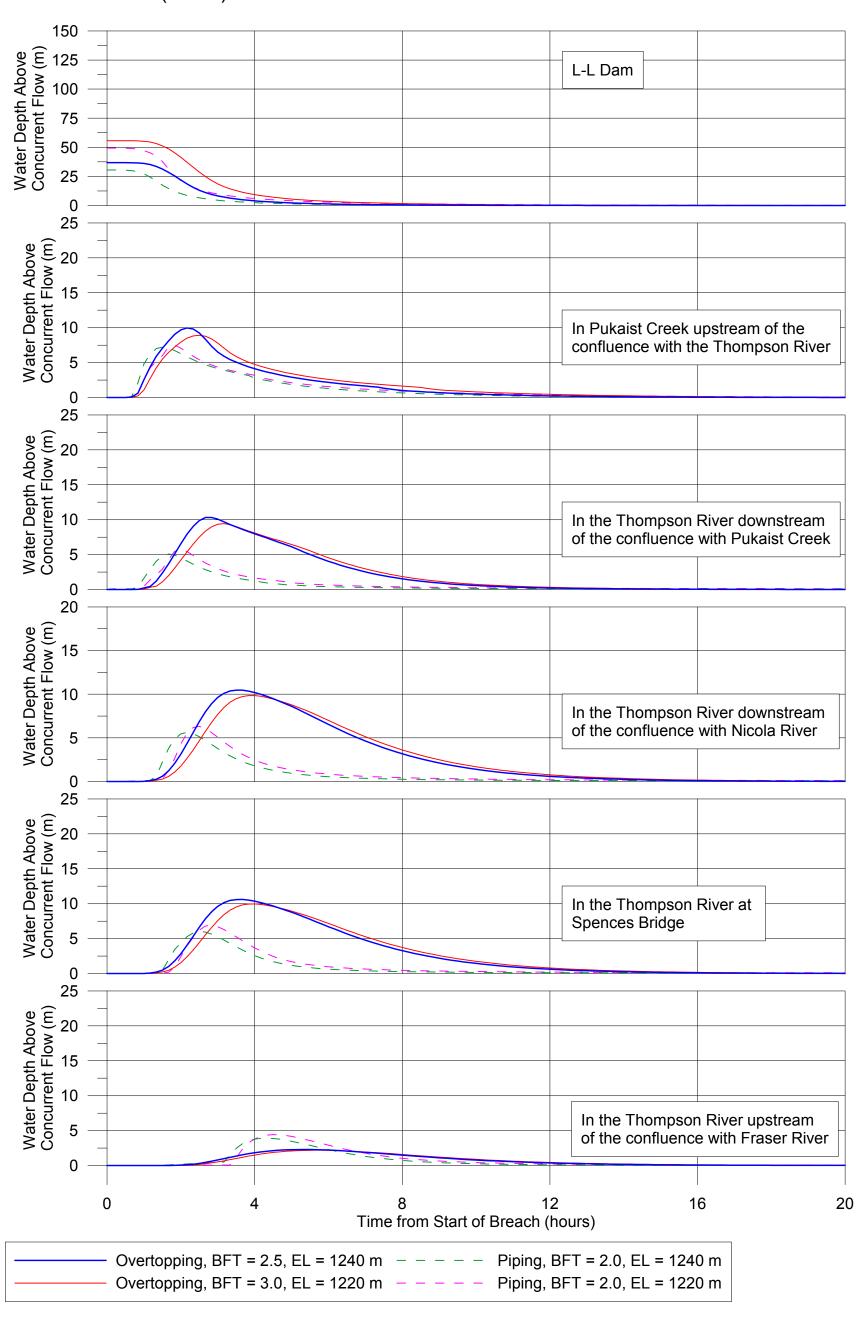
<sup>3.</sup> Elevation shown is the assumed Breach Bottom Elevation.

Figure 5.16 Piping and Overtopping Breaches, Release of Water Only - Flood Hydrographs (2 of 2)



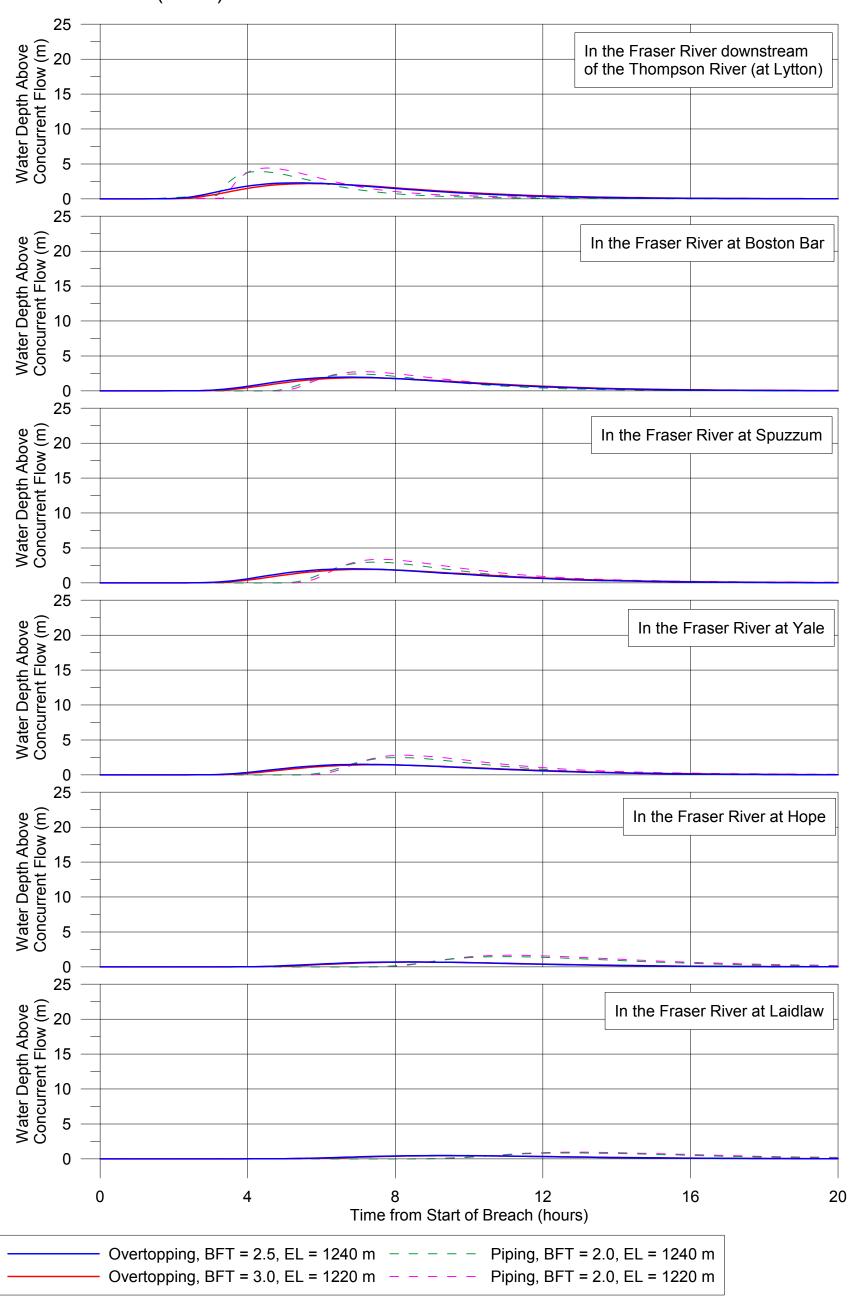
- 1. Concurrent flow in rivers downstream of dam is Probable Maximum Flow for Overtopping failure and Mean Annual Flow for Piping Failure.
- 2. BFT = Breach Formation Time in hour.
- 3. Elevation shown is the assumed Breach Bottom Elevation.

Figure 5.17 Piping and Overtopping Breaches, Release of Water Only - Stage Hydrographs (1 of 2)

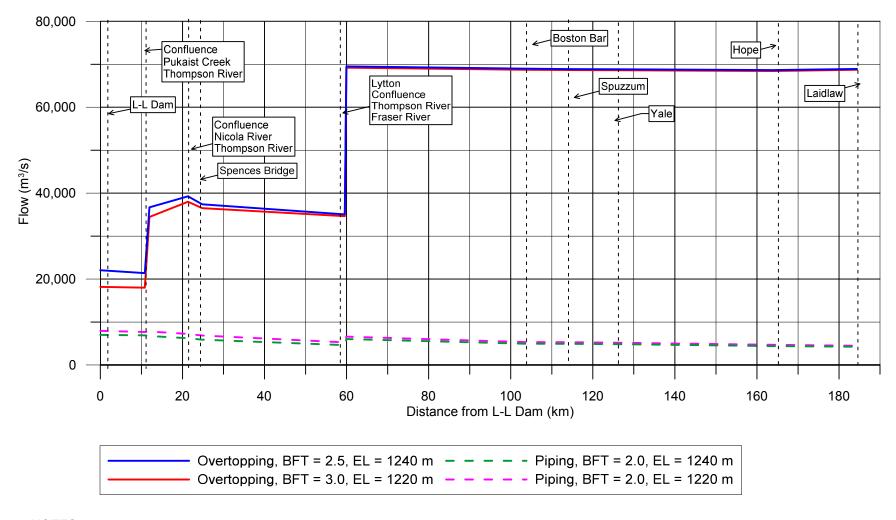


- 1. Concurrent flow in rivers downstream of dam is Probable Maximum Flow for Overtopping failure and Mean Annual Flow for Piping Failure.
- 2. BFT = Breach Formation Time in hour.
- 3. Elevation shown is the assumed Breach Bottom Elevation.

Figure 5.17 Piping and Overtopping Breaches, Release of Water Only - Stage Hydrographs (2 of 2)

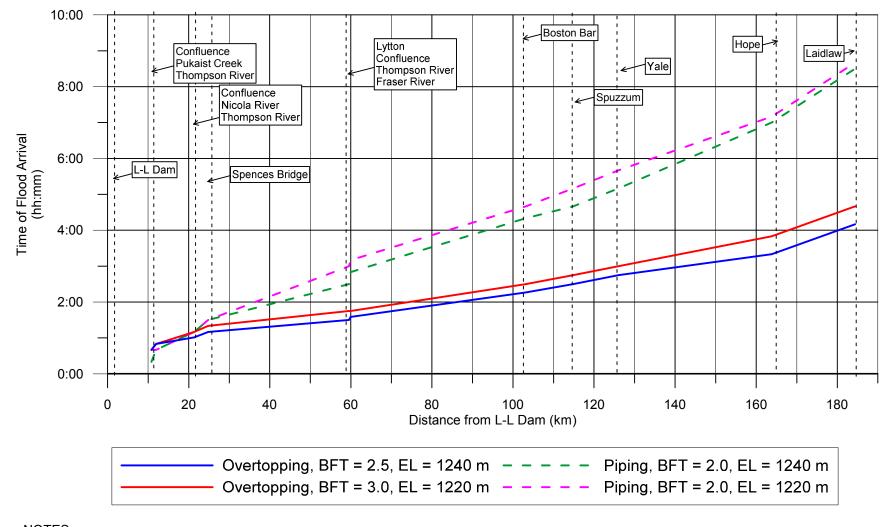


- 1. Concurrent flow in rivers downstream of dam is Probable Maximum Flow for Overtopping failure and Mean Annual Flow for Piping Failure.
- 2. BFT = Breach Formation Time in hour.
- 3. Elevation shown is the assumed Breach Bottom Elevation.



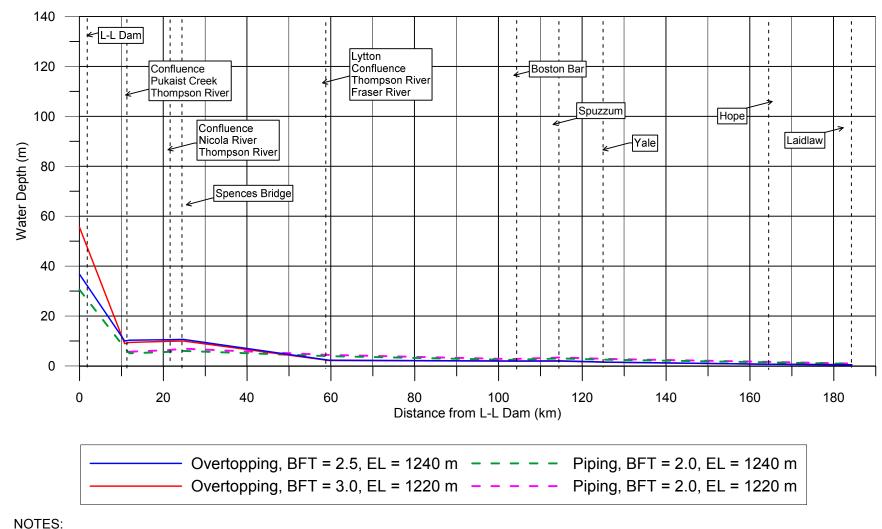
- 1. Includes concurrent flow in rivers downstream of dam: Probable Maximum Flow for Overtopping failure; Mean Annual Flow for Piping Failure.
- 2. BFT = Breach Formation Time in hour.
- 3. Elevation shown is the assumed Breach Bottom Elevation.

Figure 5.18 Piping and Overtopping Breaches, Release of Water Only - Peak Flows d/s of L-L Dam



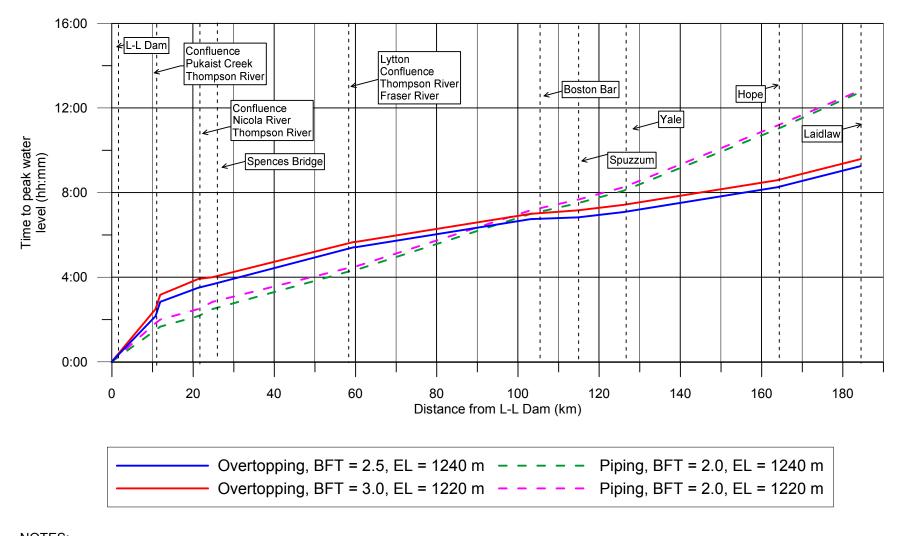
- 1. Includes concurrent flow in rivers downstream of dam: Probable Maximum Flow for Overtopping failure; Mean Annual Flow for Piping Failure.
- 2. BFT = Breach Formation Time in hour.
- 3. Elevation shown is the assumed Breach Bottom Elevation.

Figure 5.19 Piping and Overtopping Breaches, Release of Water Only - Flood Arrival Time d/s of L-L Dam



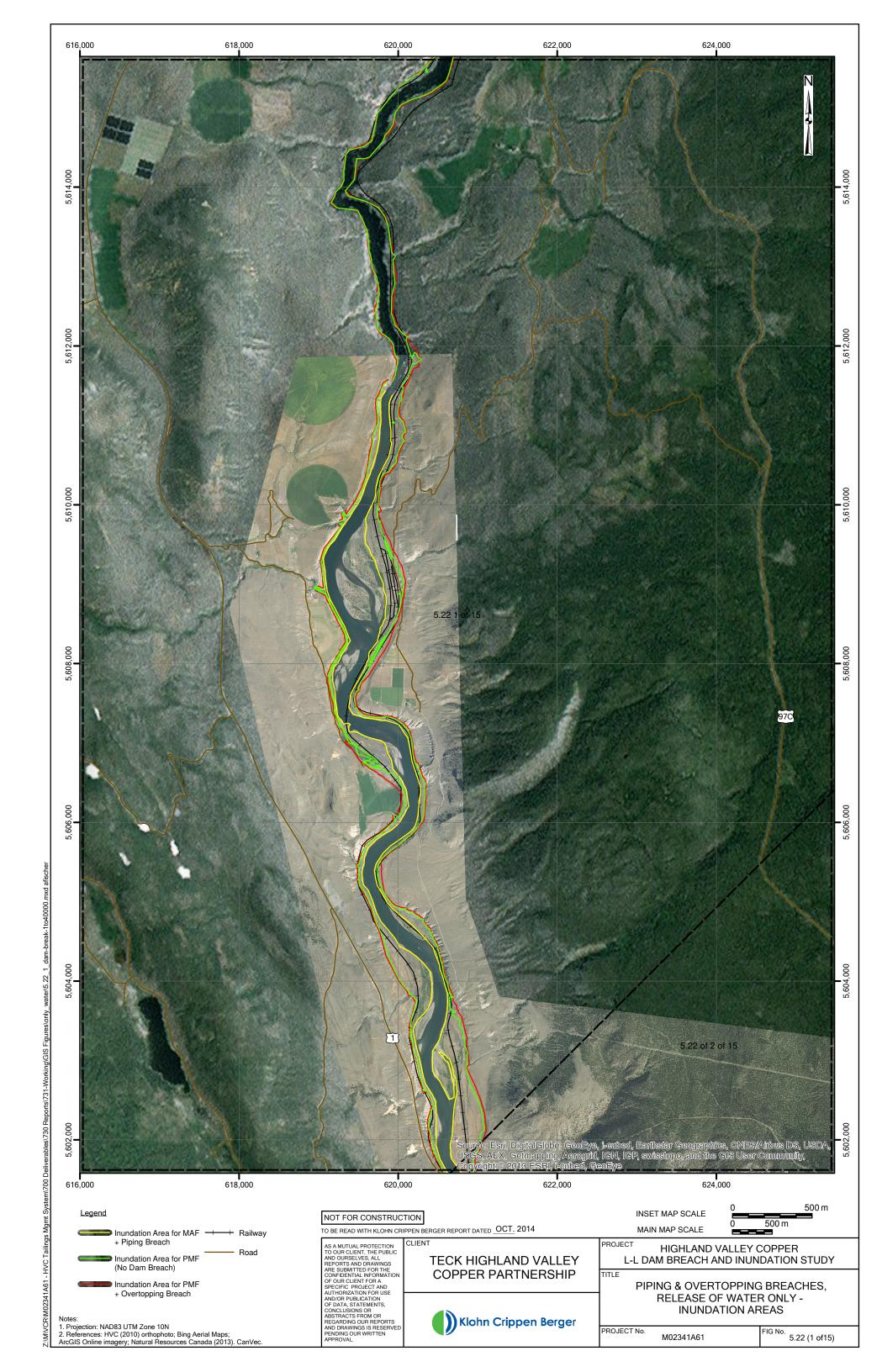
- 1. Includes concurrent flow in rivers downstream of dam: Probable Maximum Flow for Overtopping failure; Mean Annual Flow for Piping Failure.
- 2. BFT = Breach Formation Time in hour.
- 3. Elevation shown is the assumed Breach Bottom Elevation.

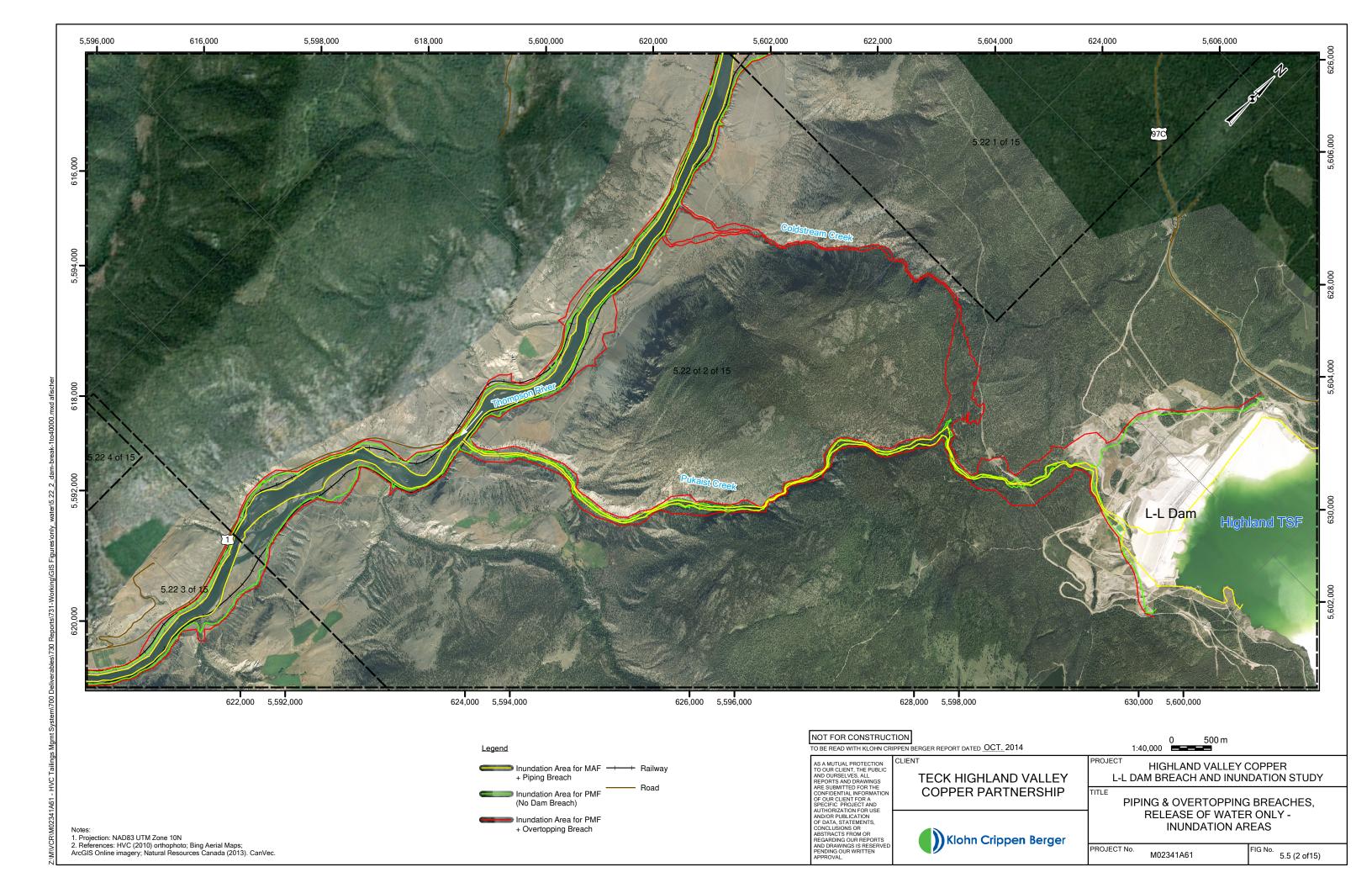
Figure 5.20 Piping and Overtopping Breaches, Release of Water Only - Peak Water Depths above Concurrent Flow d/s of L-L Dam

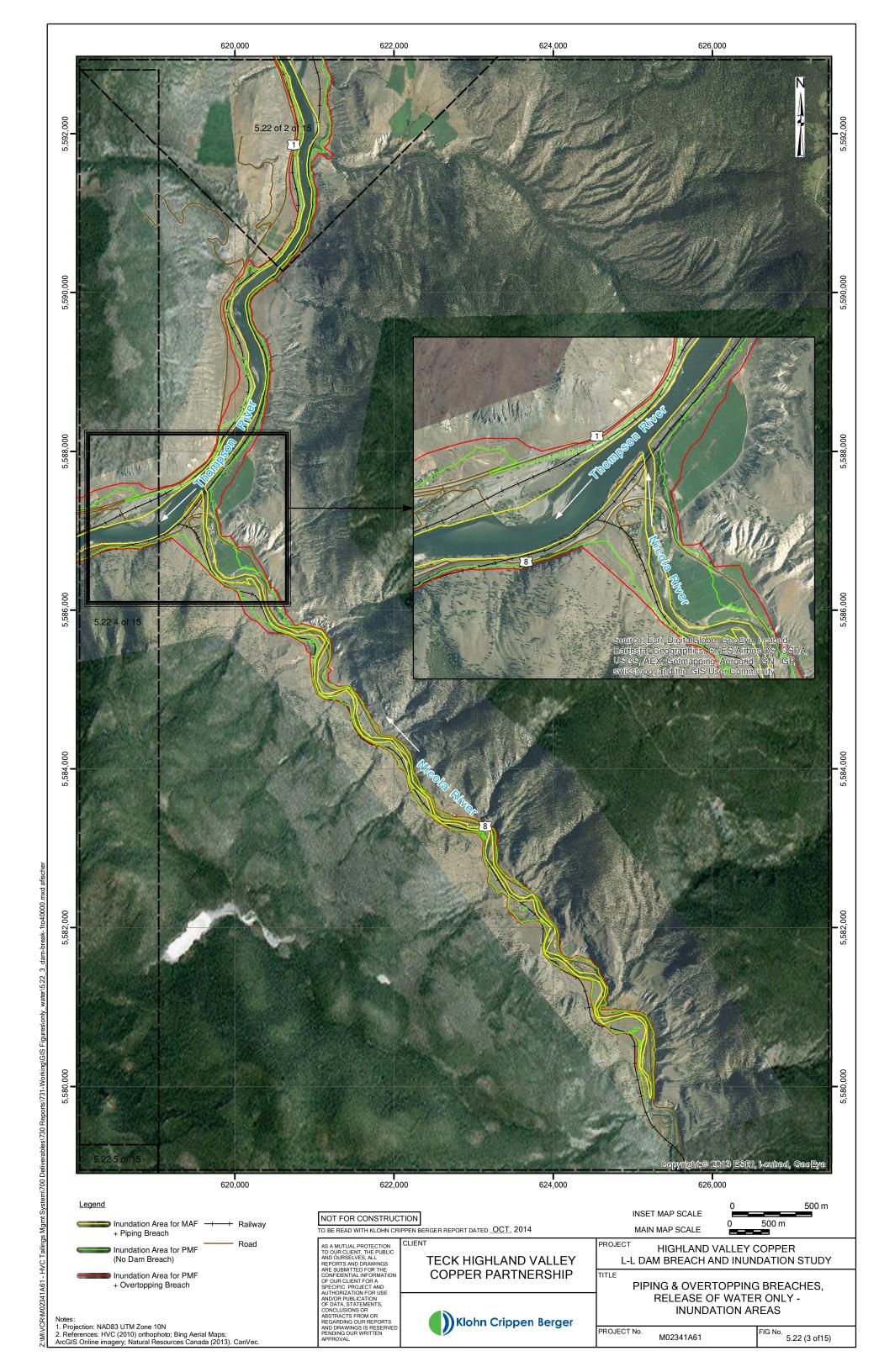


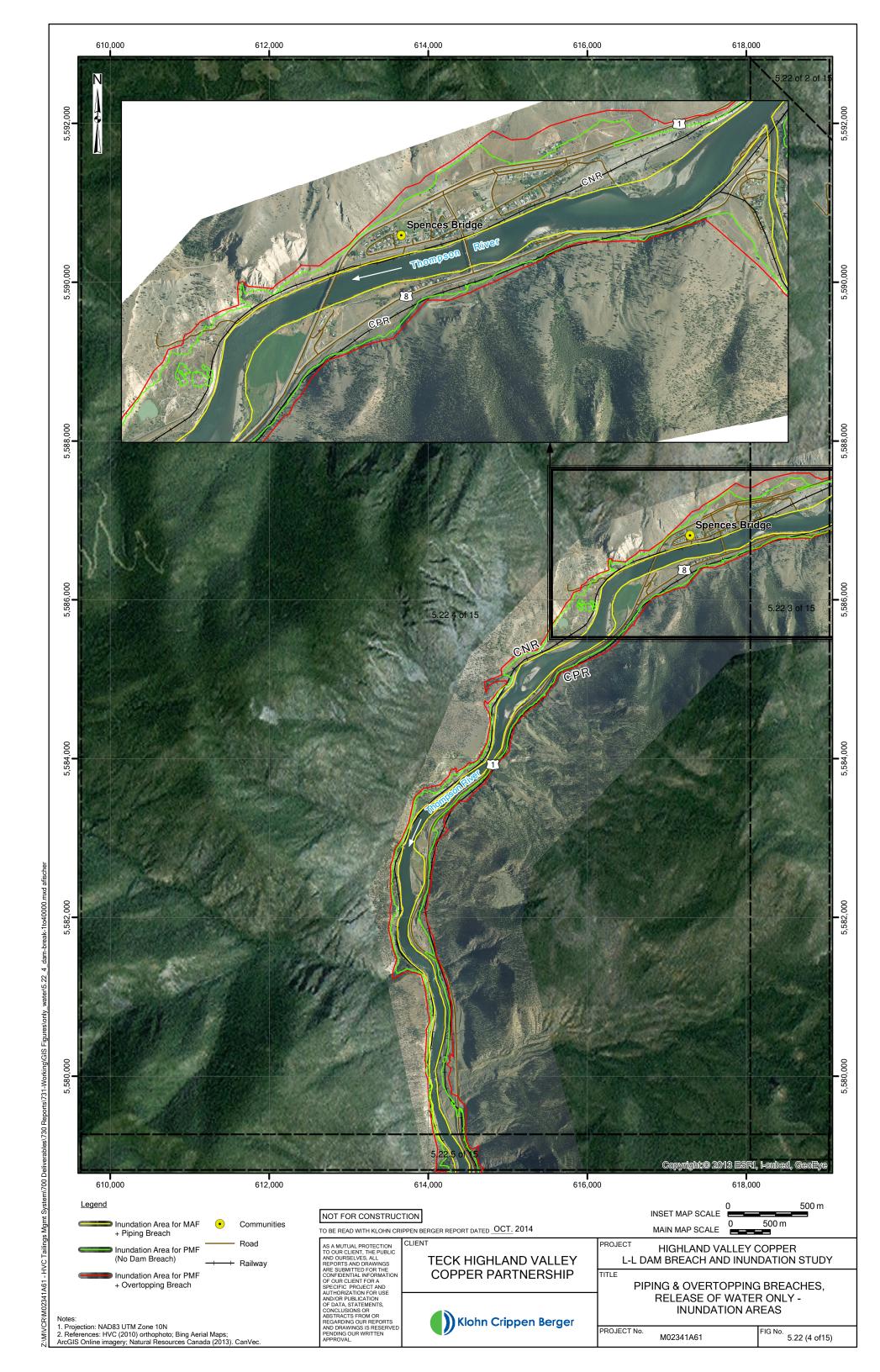
- 1. Includes concurrent flow in rivers downstream of dam: Probable Maximum Flow for Overtopping failure; Mean Annual Flow for Piping Failure.
- 2. BFT = Breach Formation Time in hour.
- 3. Elevation shown is the assumed Breach Bottom Elevation.

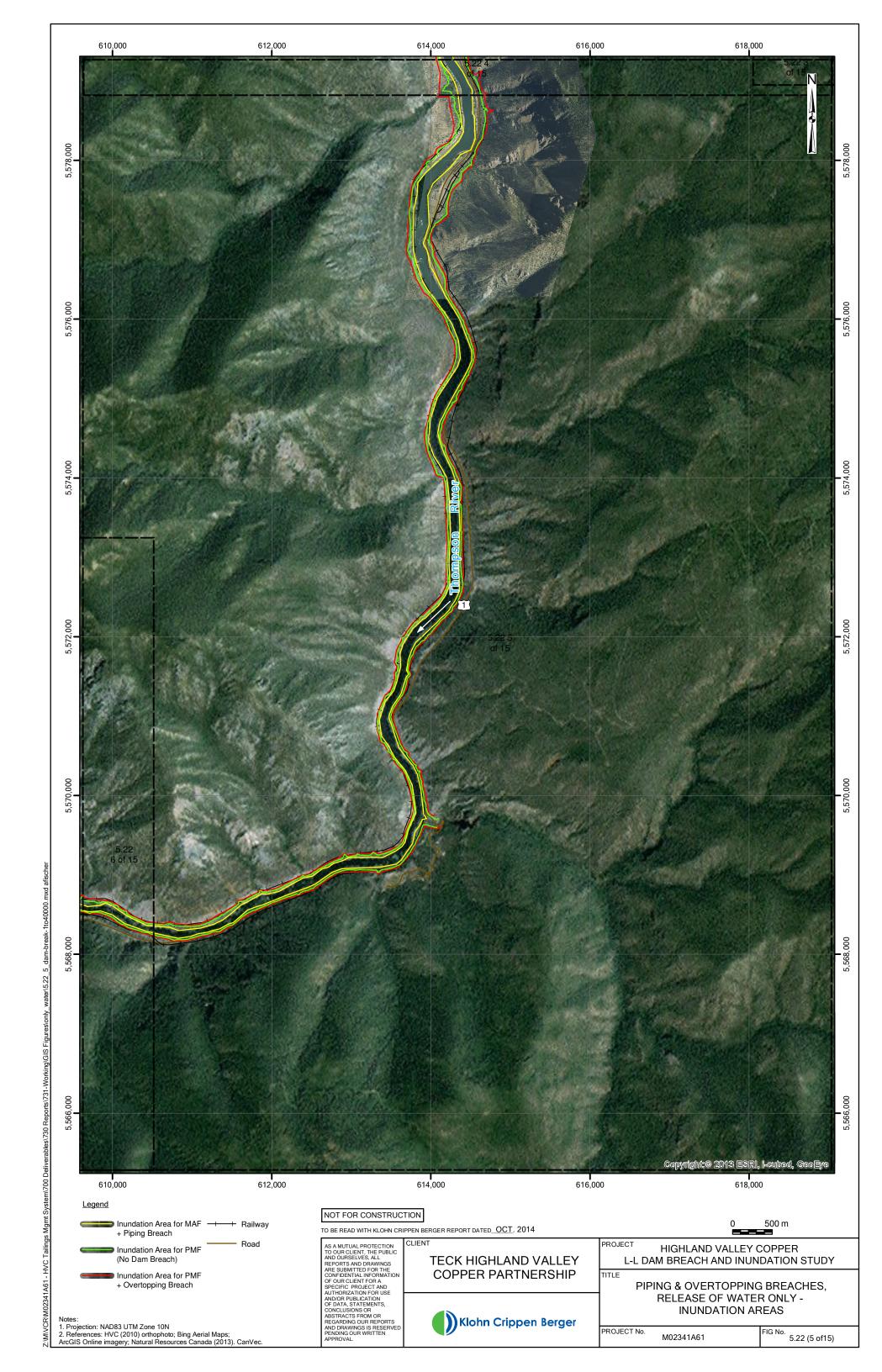
Figure 5.21 Piping and Overtopping Breaches, Release of Water Only - Time to Peak Water Level d/s of L-L Dam

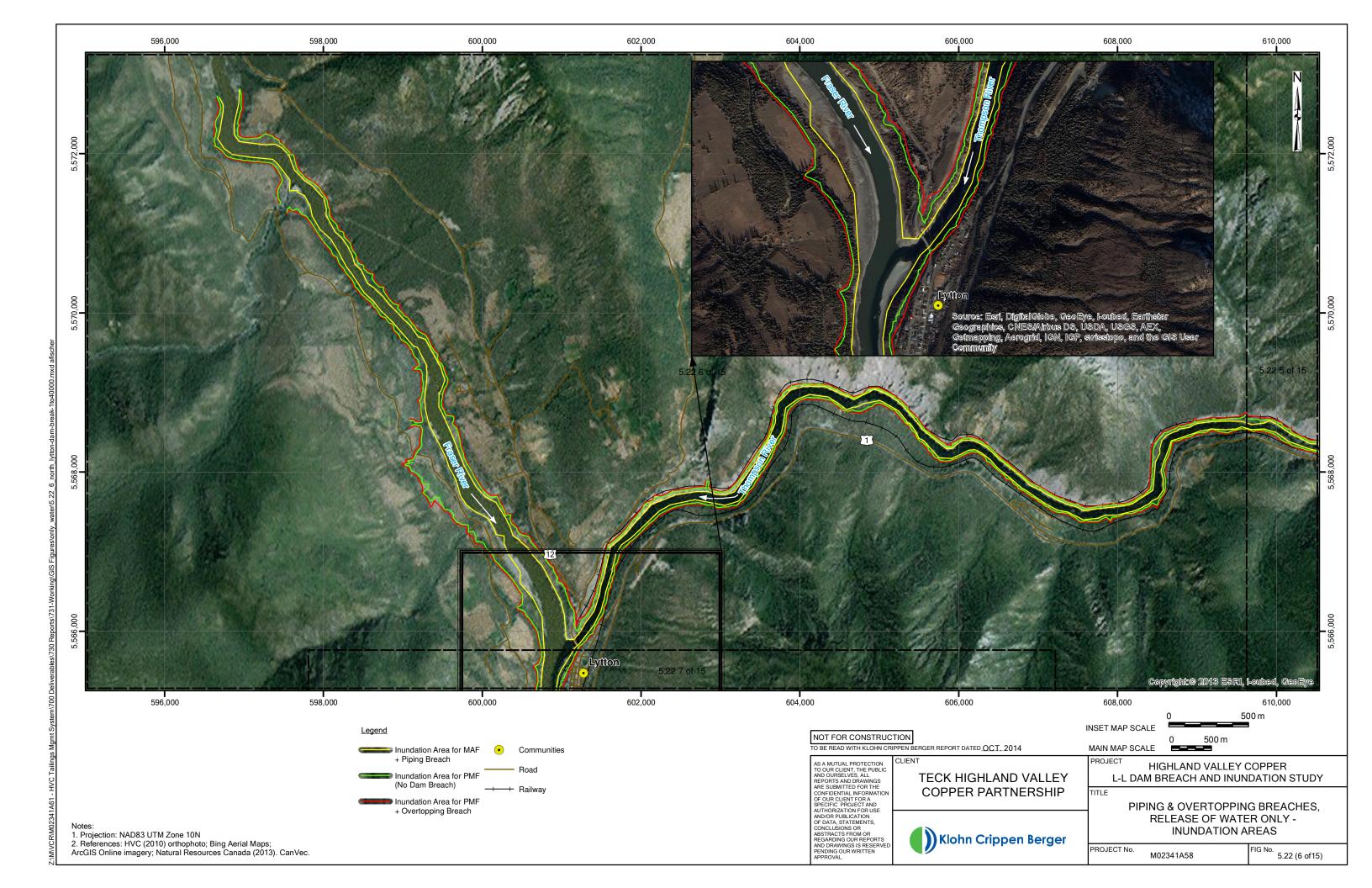


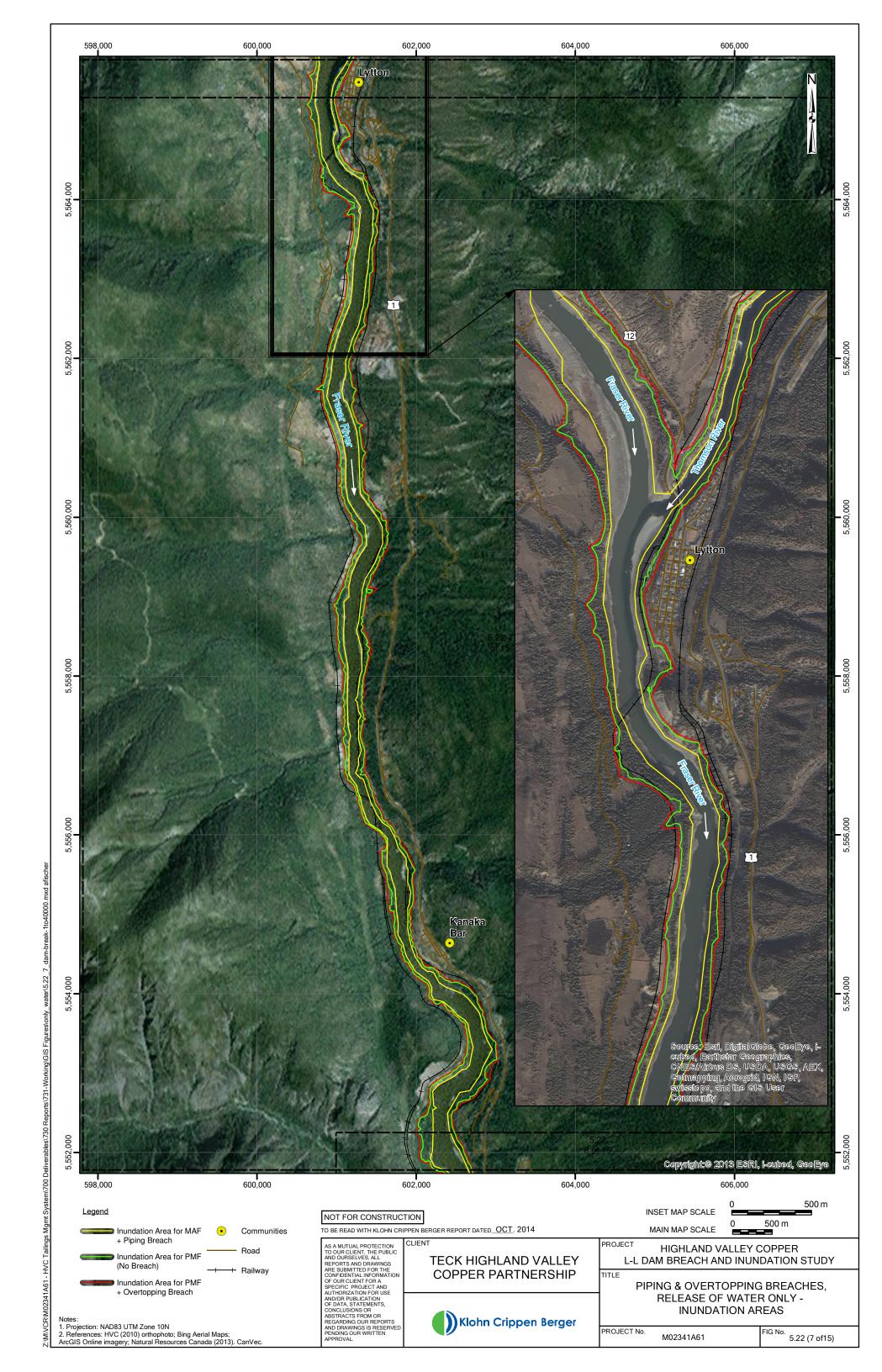


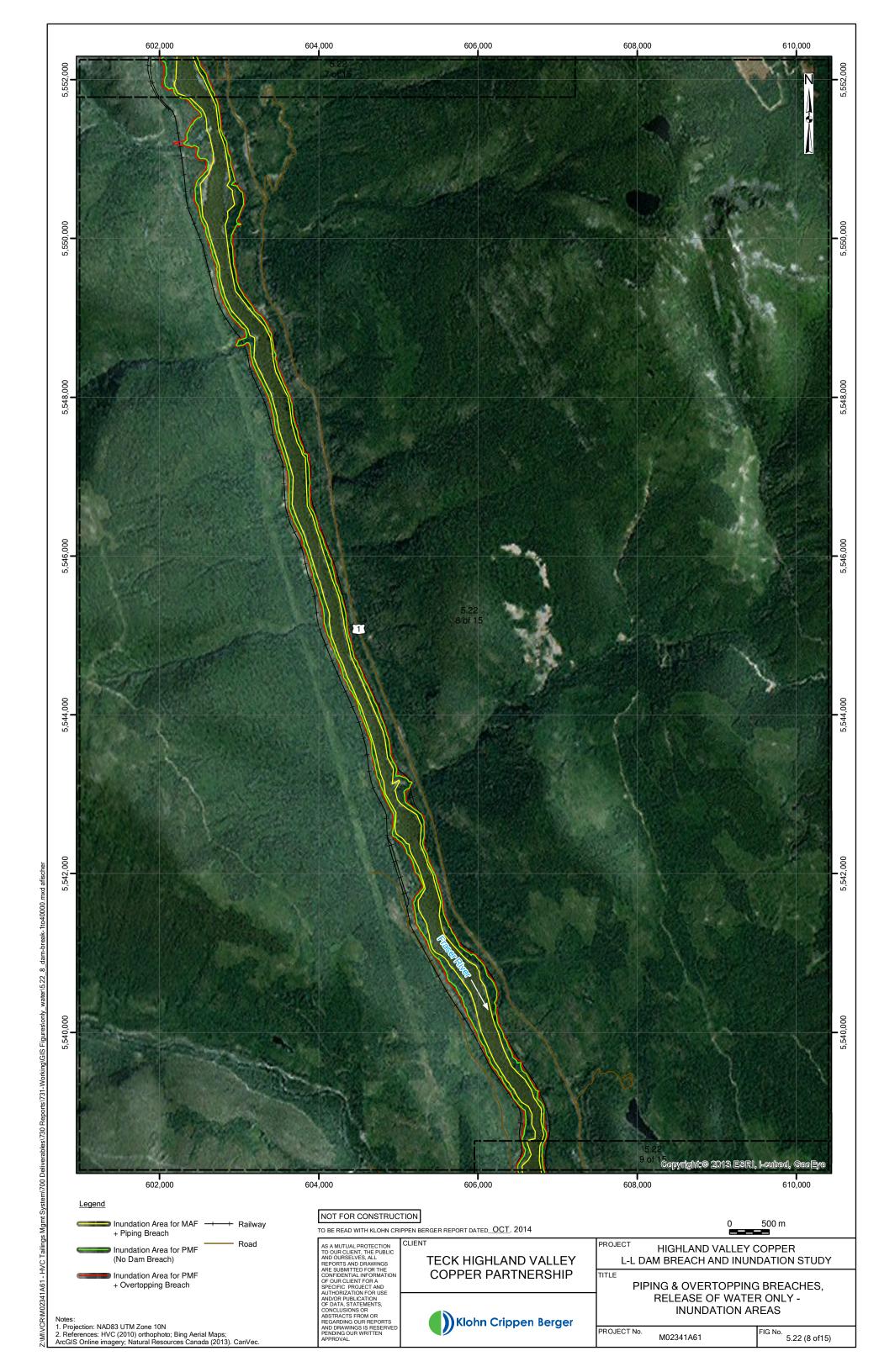


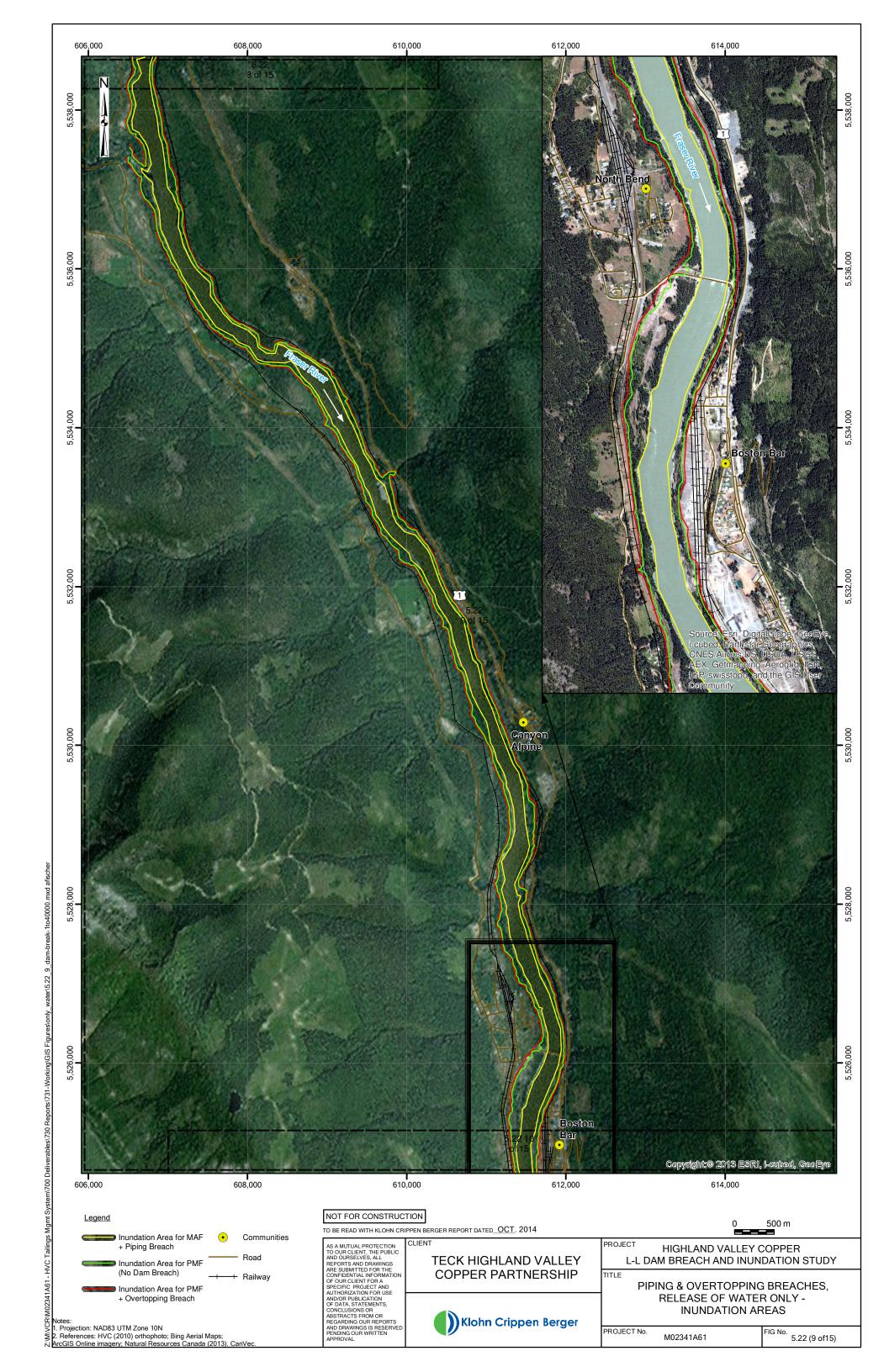


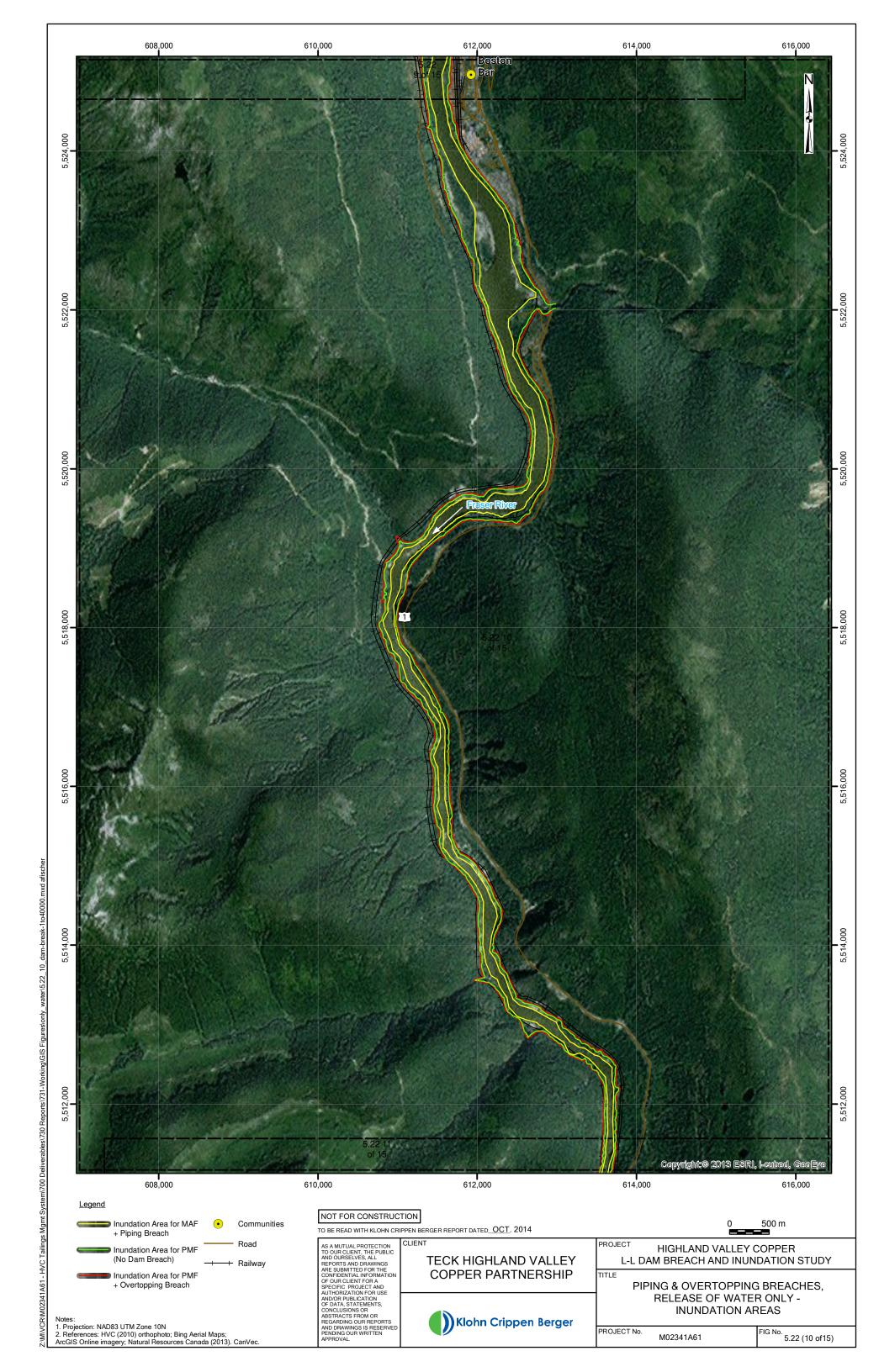


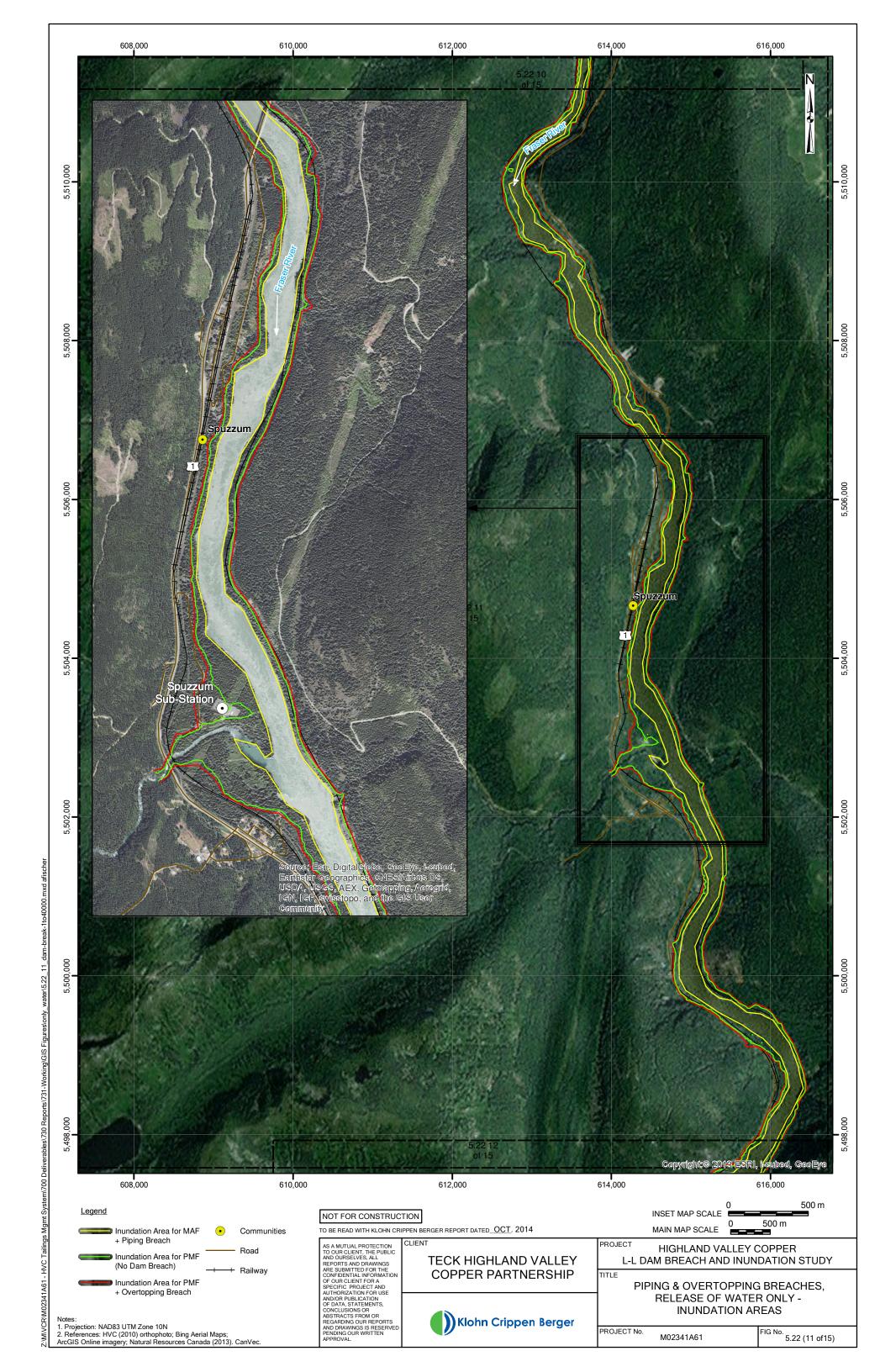


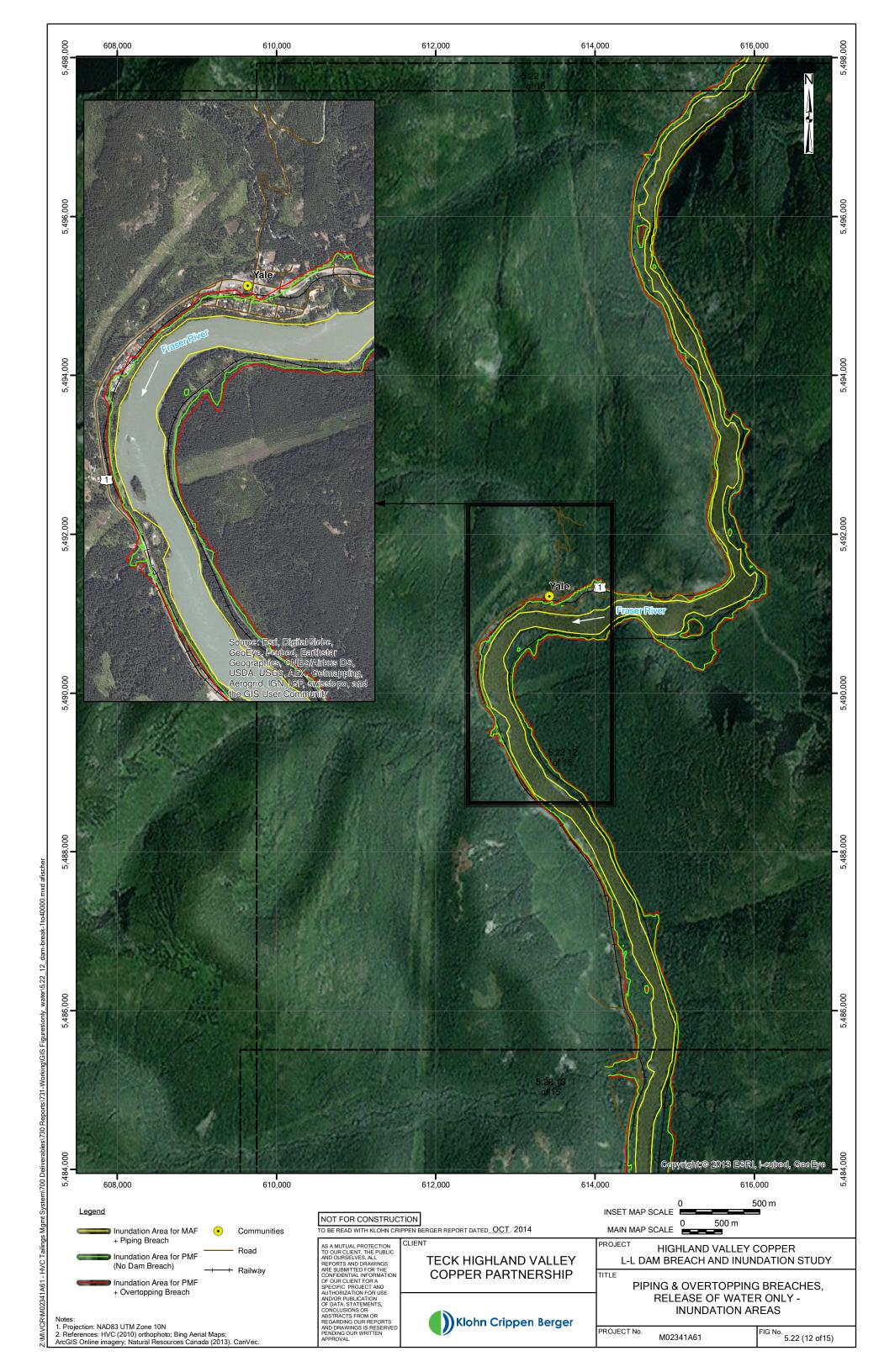


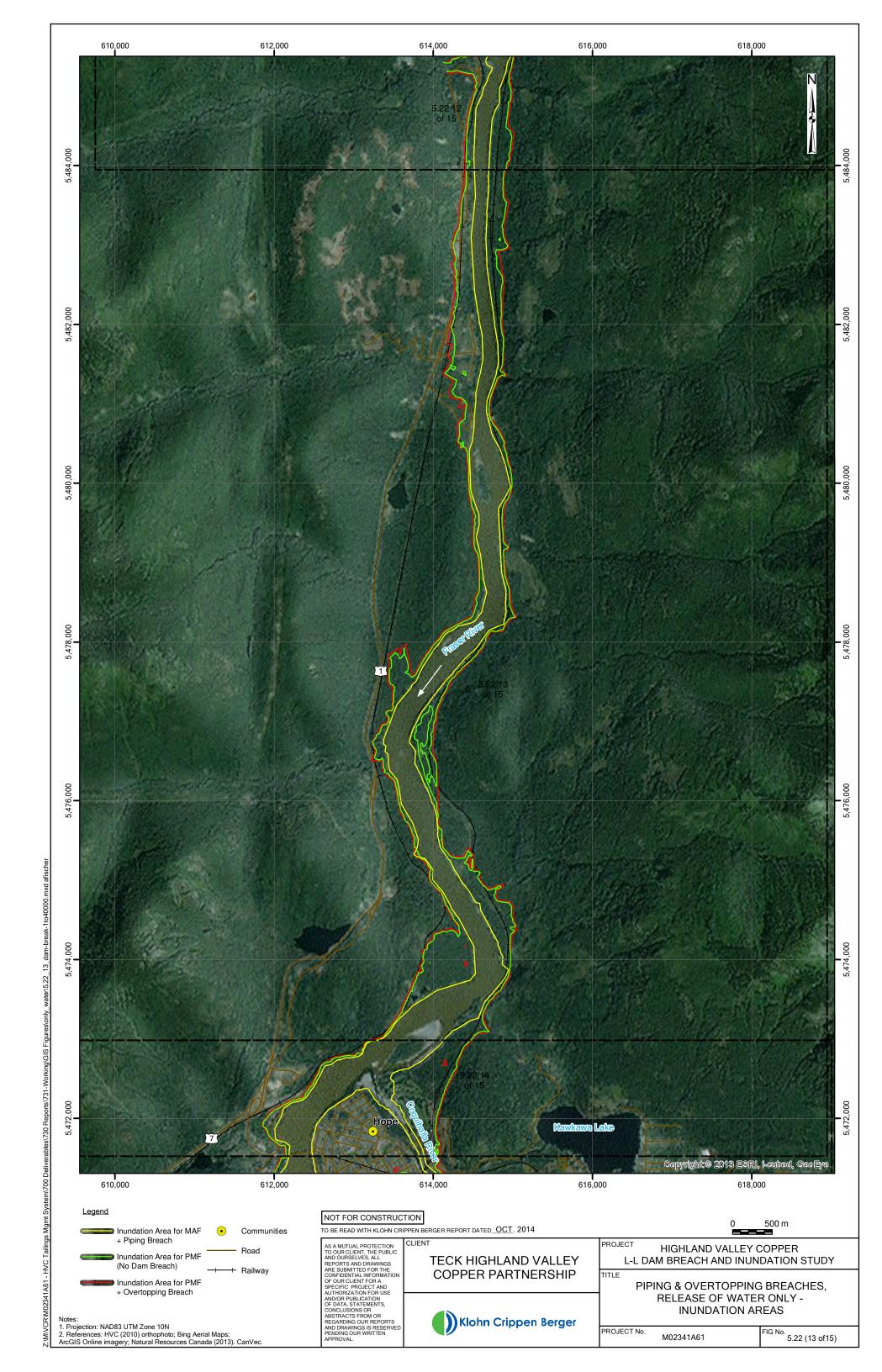


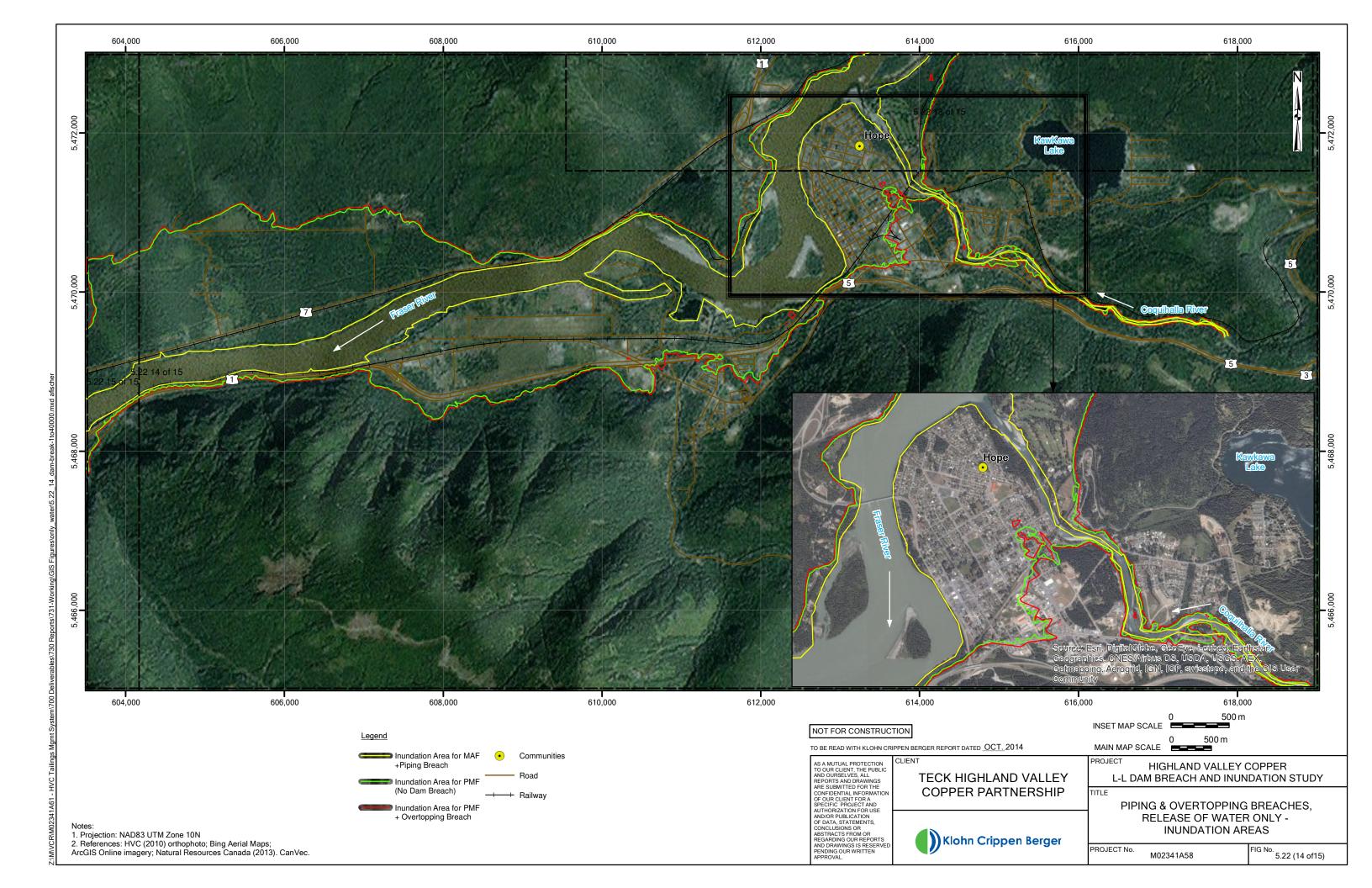


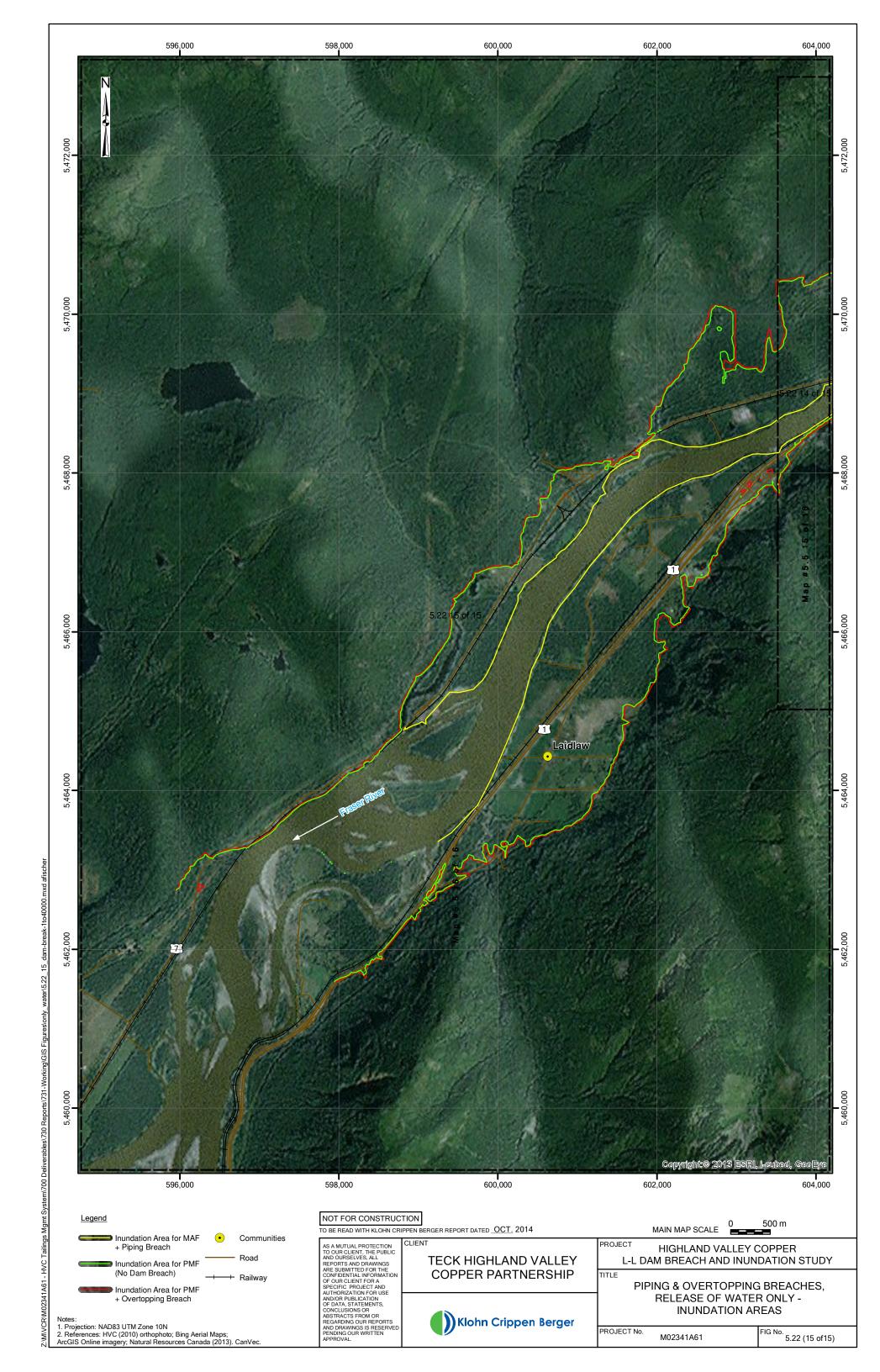












# **APPENDIX I**

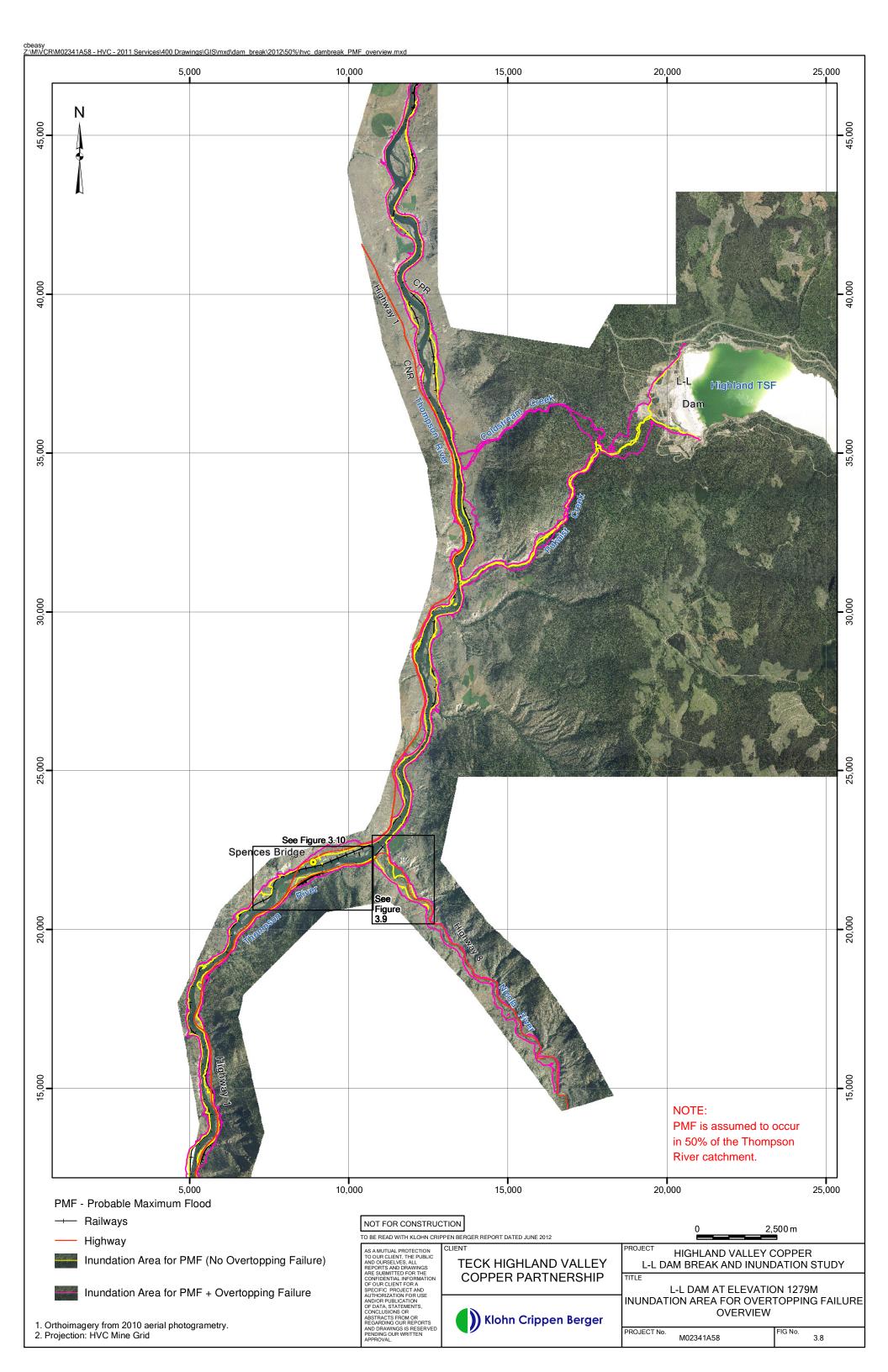
**Overtopping Breach Inundation Maps with 50% PMF** 

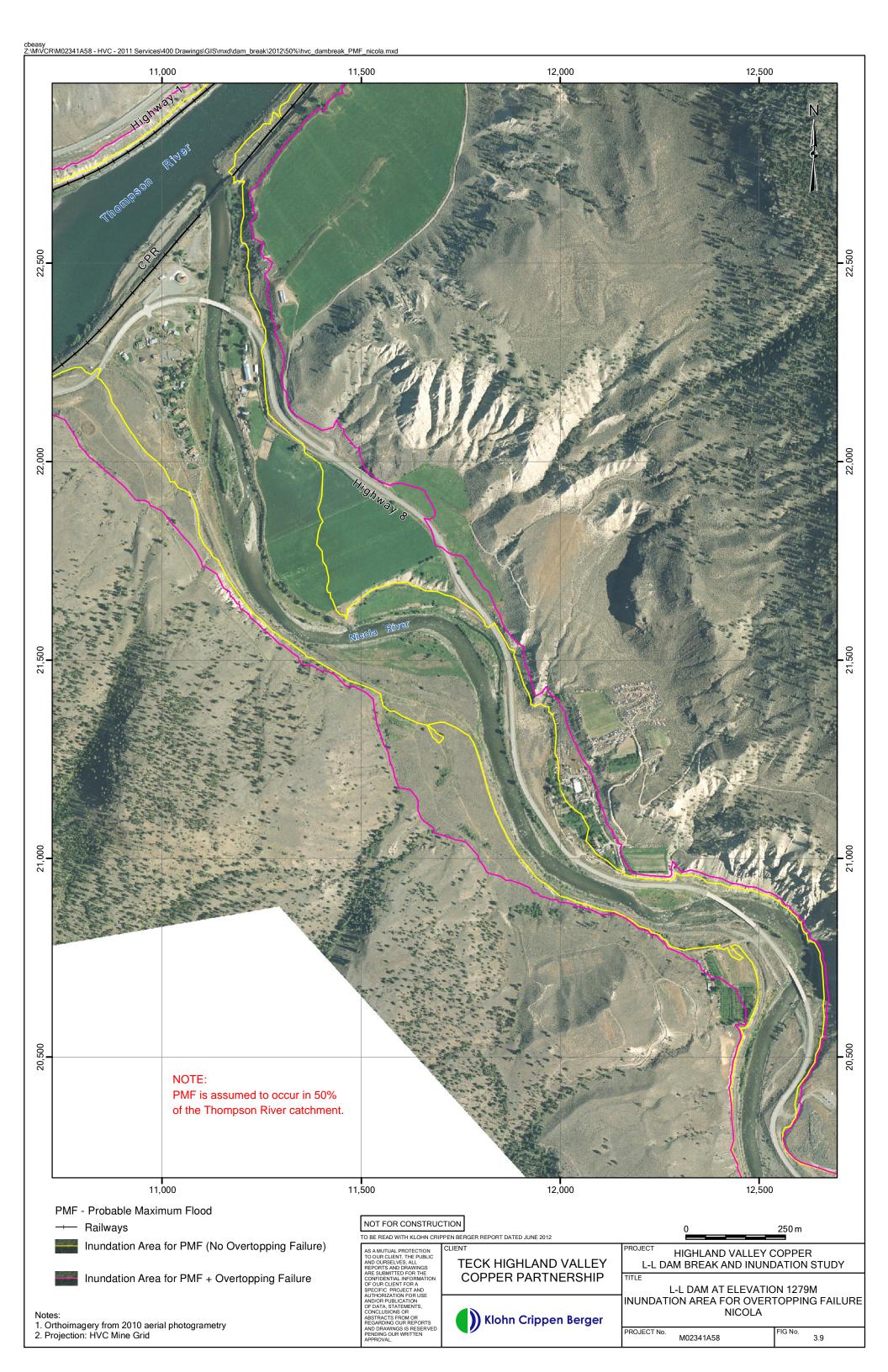
The following overtopping breach inundation maps are taken from KCB June 27, 2012 report "Highland Tailings Storage Facility, L-L Dam Break and Inundation Analysis – Dam at El. 1279 m":

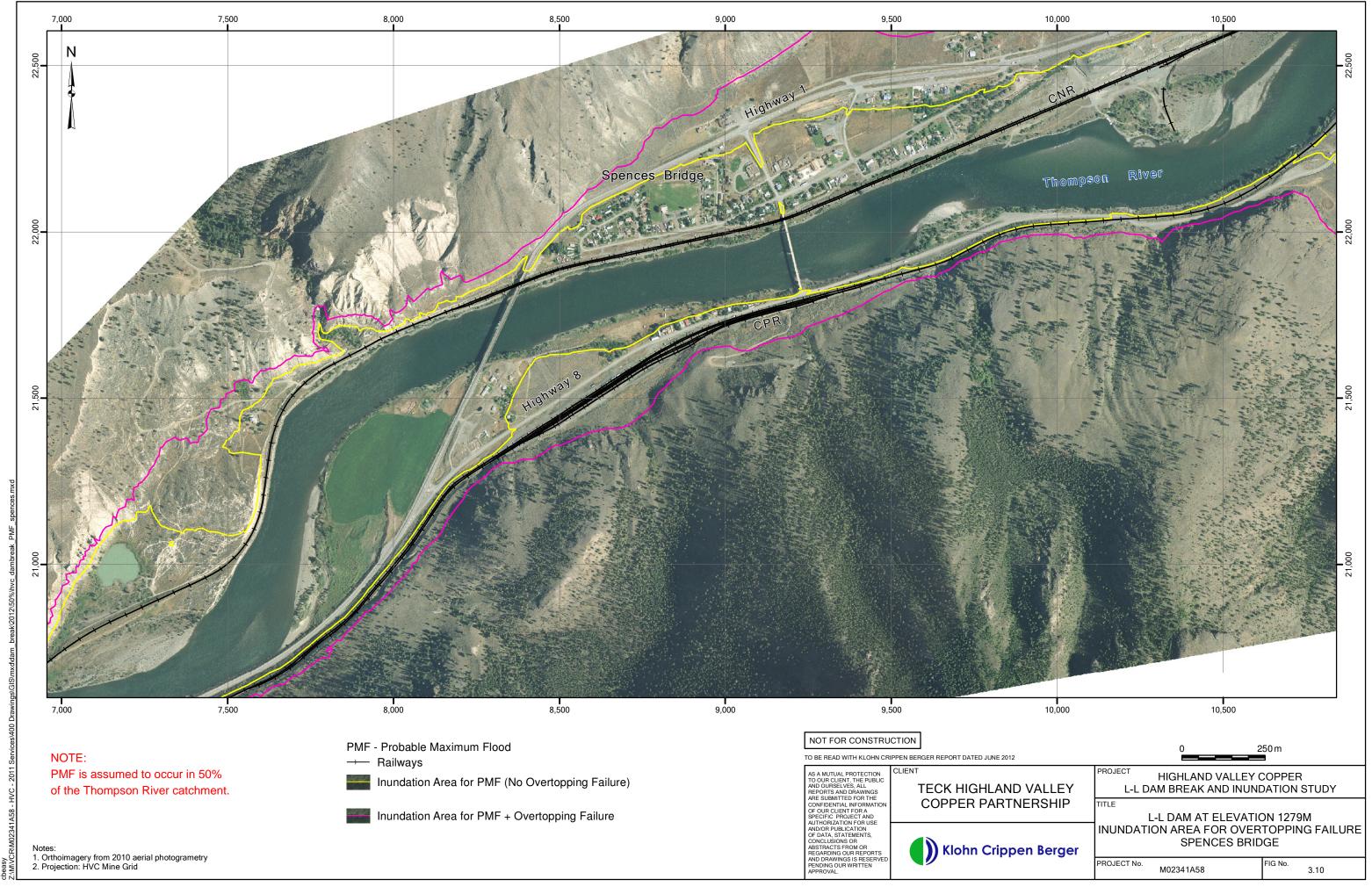
Figure 3.8	L-L Dam at El. 1279 m, Inundation Area for Overtopping Failure – Overview
Figure 3.9	L-L Dam at El. 1279 m, Inundation Area for Overtopping Failure – Nicola
Figure 3.10	L-L Dam at El. 1279 m, Inundation Area for Overtopping Failure – Spences Bridge

#### Note:

The inundation extents shown on these figures are based on the assumption that the probable maximum flood (PMF) occurs over only 50% of the Thompson River catchment.







cbeasv